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# VERNON-HARCOURT

ON

# THE RIVER SEINE.

# THE RIVER SEINE.

BY

LEVESON FRANCIS VERNON-HARCOURT, M.A.,

M. INST. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

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# THE INSTITUTION OF CIVIL ENGINEERS.

16 February, 1886.

SIR FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

(*Paper No. 2122.*)

## "The River Seine."

By LEVESON FRANCIS VERNON-HARCOURT, M.A., M. Inst. C.E.

THE Seine is the most important river of France, both on account of its being the highway for a flourishing inland trade, and in consequence of the extensive engineering works which have been carried out for its improvement. Its basin has also formed the subject of very careful hydrological investigations, for it was on the Seine that the systematic prediction of floods was first established, which has since been adopted for other French rivers. Like the Thames, it flows past the capital of the country, to which fact it owes a portion of its importance, though the centres of maritime trade to which it gives access are situated lower down; like the Thames, also, it has been made the receptacle for the sewage of the largest city on its banks, though recently it has been relieved of a portion of this nuisance by the establishment of extensive irrigation works on the plains of Gennevilliers (Plate 2, Fig. 1). Unlike the Thames, however, its estuary, being less favoured by nature, has afforded scope for important works of tidal-river improvement; and the distance of Paris from the sea has led to a more thorough extension of its inland navigation.

Though references to the Seine, by the Author and others, will be found in several volumes of the "Minutes," yet neither in the Proceedings of the Institution, nor, as far as the Author is aware, in France, has a comprehensive Paper on the River Seine as a whole been hitherto published. The Author thinks that such a Paper, in a condensed form suitable for the "Minutes," cannot fail to possess much interest for engineers, owing to the great advantages afforded by giving timely warning of floods, and adopting measures for their mitigation, the large, varied, and novel works which have been executed for the improvement of the

river, and the important extensions still in progress or contemplated.

The Author proposes to investigate the subject under three distinct aspects, namely: I. Hydrology of the Seine basin; II. Inland navigation improvement-works; and III., Estuary-works. The able reports of the late Mr. Belgrand, on the prediction of the floods of the Seine, drew the Author's attention to that branch of the subject more than ten years ago. He has also had occasion, for some time past, to study the Seine under its other two aspects; having visited the Seine several times for this special purpose, and availed himself of the opportunity of discussing the question with the French engineers in charge of different sections of the river; and having brought the subject under the notice of the Institution, in a brief and somewhat fragmentary form, in portions of his Papers on "Fixed and Movable Weirs," [1] and "Harbours and Estuaries on Sandy Coasts." [2] By invitation from the Council of the French Association for the Advancement of Science, he attended their Congress at Rouen in August 1883, when the extension of the Seine training-works, and the conversion of Paris into a seaport, were the subjects to which the members of the engineering section of the Association specially devoted their attention, in the discussion of which he had the honour to take part.[3] It was also his privilege to inspect the estuary-works, in April 1883, in company with the late Mr. Lavoinne, then Engineer-in-Chief of the tidal Seine, who, in a memoir [4] published since his death, has left his views on the extension of the training-walls as a valuable legacy to his successors.

## I. HYDROLOGY OF THE SEINE BASIN.

The area of the Seine basin is 30,370 square miles, of which 3,750 consist of sloping impermeable strata, 3,760 of flat impermeable strata, and 22,860 square miles of permeable strata; so that the permeable strata occupy about three-fourths of the basin. The flat impermeable strata, moreover, have little influence in the production of torrential floods, and therefore practically only about one-eighth of the basin is of a strictly torrential character (Plate 1, Fig. 1). Accordingly the Seine possesses the

[1] Minutes of Proceedings Inst. C.E. vol. lx. p. 30. [2] *Ibid.*, vol. lxx. p. 20.
[3] Association Française pour l'Avancement des Sciences, 12e Session, Rouen, 1883, p. 293.
[4] "La Seine Maritime et son Estuaire." E. Lavoinne. 1885.

characteristics of a gently-flowing river, differing in this respect from the other principal rivers of France, the Rhone, the Loire, and the Garonne, whose basins consist mainly of impermeable strata.

The Seine itself has been divided into four natural sections, with distinctive appellations; namely, the Little Seine, from its source to its confluence with the Yonne at Montereau; the Upper Seine, from Montereau to Paris, just above which place one of its most important tributaries, the Marne, flows in; the Lower Seine from Paris to St. Aubin, near Elbeuf, at the limit of the tidal flow; and the Tidal Seine, from St. Aubin to the sea (Plate 2, Figs. 1, 2, and 3.) The principal tributaries which join the main river above Paris are, the Yonne, having a basin of 4,300 square miles, larger than the area of 3,958 square miles drained by the Little Seine, which it joins at Montereau; the Loing, which flows in $8\frac{3}{4}$ miles below Montereau, whose basin is 1,786 square miles; and the Marne, which drains an area of 5,290 square miles. The Aisne, with a basin of 3,282 square miles, unites with the Oise at Compiègne; and the Oise, whose basin has an area of 3,359 square miles, discharges the flow of the combined rivers into the Lower Seine, a little above Poissy. The Eure, having a basin of 2,216 square miles, falls into the Lower Seine at Pont de l'Arche, and is the lowest tributary of any note which flows into the main river; for the Rille, draining a comparatively small area, discharges into the estuary just below the ends of the training-walls. (Plate 1, Fig. 1).

## Flood Characteristics of the Tributaries.

Since the character of the floods of a river depends mainly upon the permeability or impermeability of the strata forming its basin, each valley has to be separately considered, in order to ascertain the nature of the flow of each tributary, and the influence of the tributaries on the main river (Plate 1, Fig. 1). None of the principal tributaries of the Seine flow exclusively over impermeable strata; but the upper part of the basin of the Yonne, being both impermeable and steep, imparts a torrential character to the river (Plate 1, Figs. 4 and 10), though not quite one-half its whole basin consists of impermeable strata (Plate 1, Fig. 1). Nearly one-half of the Marne basin is composed of impermeable strata (2,361 square miles out of 5,290 square miles); and the Marne, in the upper portion of its course, has a very marked torrential flow (Plate 1, Fig. 12). This

torrential character of the river is somewhat lost in its flow through the central permeable strata, and is not fully regained in the impermeable strata forming the lower basin, owing to the flatness of this part of the valley, though reinforced by the influx of some torrential streams, and notably the Grand Morin (Plate 1, Fig. 6). The Loing has the most impermeable basin of all the main tributaries, for four-fifths of its basin consist of impermeable strata. The flatness, however, of these strata, combined with a small average rainfall, causes the floods of the Loing to have comparatively little influence on the main river. The basin of the Little Seine and the Aube is traversed, about half-way up, by a band of impermeable strata; but as these strata occupy only about one-sixth of the area of the basin, and the other strata are permeable, the flow of the Little Seine is gentle before its confluence with the Yonne (Plate 1, Figs. 3 and 9). Of the main tributaries flowing into the Lower Seine, the Aisne has a wholly permeable basin, and the Oise and the Eure drain very small portions of impermeable strata. In fact, of the whole area of about 12,830 square miles draining into the Lower Seine, only 2,720 square miles consist of impermeable strata, of which six-sevenths are flat. Accordingly, the Yonne and the Marne are the only affluents which tend to impart a torrential element to the Seine floods, and give these floods a mixed character at Montereau and Paris (Plate 1, Figs. 5, 7, 11, and 13) just below the confluence of these rivers.

The influence of the nature of the strata on the floods of a river is clearly seen by comparing the flood diagrams, from November to January 1882–3, of the Little Seine at Bray, and the Aisne at Pontavert (Plate 1, Figs. 9 and 14), with the Yonne at Sens and the Marne at St. Dizier (Plate 1, Figs. 10 and 12). The different appearance of the floods of the Seine at Bray and at Montereau (Plate 1, Figs. 3, 5, 9 and 11), indicates the disturbance produced by its junction with the Yonne (Plate 1, Figs. 4 and 10); and this disturbance is still further accentuated at Paris (Plate 1, Figs. 7 and 13) by the influx of the torrential Marne (Plate 1, Figs. 6 and 12). On the contrary, the gently-flowing Aisne (Plate 1, Figs. 8 and 14) and Oise have a regulating influence on the floods of the Lower Seine, as experienced at Mantes (Plate 1, Fig. 15). The Eure has little effect on the Seine floods, for, owing to its permeable basin and the small average rainfall, its flood-rise is small except after a thaw.

## Rainfall of the Seine Basin.

The Seine basin is subject to similar meteorological influences, so that the special character of any particular season, whether wet or dry, is experienced throughout the whole basin, though the actual amount of rainfall varies with the locality.

The average amount of rainfall over the whole basin, in the twenty-three years from 1861 to 1883, amounted to 27·24 inches. In 1870 it fell as low as 19·37 inches, whilst in 1866 it reached 38·03 inches.

The rainfall at different places in the Seine basin depends primarily on their altitude, and on their proximity to the sea. Thus the largest average rainfall of 79·57 inches occurs at Haut-Folin in the Morvan district, the highest point of the basin, 2,960 feet above the sea-level, and the smallest of 19·84 inches at Paris, in the central part of the basin, at an altitude of 161 feet; whilst the rainfall increases again on approaching the sea, reaching 30·12 inches at Rouen with an altitude of only 20 feet above the sea, and 38·62 inches at Yvetot, having an elevation of 485 feet. The general distribution of the rainfall over the basin is indicated in Plate 1, Fig. 2. A comparatively dry zone, where the average annual rainfall does not attain 24 inches, extends right across the basin, with Paris in the centre, and including Mantes, Courville, Melun, and Compiègne; and a portion also of the Gatinais district is similarly circumstanced. A great part of the rest of the basin, both to the east and west, has an average rainfall ranging between 24 and 32 inches; whilst only near the sea-coast to the the west of Rouen, and near to the north-eastern and south-eastern limits of the basin, are higher averages experienced. Only small portions of the Soissonnais, La Montagne, and Morvan districts reach an average of more than 40 inches; whilst the highest part of the Morvan district, at the extreme limit of the basin, alone exceeds 48 inches.

For the purposes of hydrological investigations, Mr. Belgrand found it advantageous to divide the year into two equal portions; namely, the hot season, extending from the 1st May to the end of October, and the cold season comprising the other six months. The annual diagrams of the water-levels of the Seine and its tributaries are drawn up in accordance with these divisions, commencing with May of one year and ending with April of the following year (Plate 1, Fig. 15); but the rainfall observations still follow the civil year, so that the years of the two returns do not coincide.

Nevertheless an analysis has been made of the rainfall observations at some of the stations, making them correspond with Mr. Belgrand's divisions. Out of the fourteen typical cases selected, only the two wettest, namely, Settons, in the high part of the Morvan district, and Yvetot, have on the average a greater rainfall in the cold season than in the hot, amounting to 54 per cent. in the winter at Settons, and 51 per cent. at Yvetot. At Bar-le-duc, the next most rainy station on the list, the average amounts of rainfall in the hot and cold seasons are exactly equal; but at all the other stations, the summer rainfall exceeds that of the winter, reaching a maximum of 60 per cent. at Paris, or half as much again as that of the winter rainfall, the difference between the rainfall of the two seasons being the greatest where the total rainfall is the least. The calculations of the averages for the two seasons have not been carried back beyond 1873; but since that year, up to 1884, the extremes of the average rainfall throughout the basin have been 6·10 inches (1873–74) and 17·24 inches (1876–77) in the cold season, and 11·61 inches (1874) and 19·64 inches (1878) in the hot season. These returns indicate that the cold season is quite as much subject to periods of dryness as the hot season; whilst in the few years for which statistics are given, the range of variation is greater in the cold season. The distribution, however, of the rainfall throughout the basin is more uniform in the winter months, both in average and extreme years, than in the summer, owing to the local predominance of summer storms.

## Floods of the Seine.

Although the rainfall over the Seine basin is greater in the summer than in the winter months, yet, owing to the evaporation and the dryness of the soil in the hot season, the rains of summer have comparatively little influence on the flow of the river. Any rains falling between the middle of May and the middle of October produce little effect on the river, except under very unusual conditions; whereas any heavy rain during the winter months, falling upon a saturated soil when evaporation is inactive, causes a flood, of which the height depends upon the amount of saturation of the basin by previous rains and the duration of the fall. Accordingly the occurrence of high floods is due to the concentration of the rainfall at special periods of the year, and not to a high average rainfall throughout the year. These fundamental principles are amply verified by the diagrams (Plate 1, Fig. 15) representing the daily height of the Seine at Mantes from May 1st, 1872, to April

30th, 1884. All the floods of the Seine during those twelve years occurred during the cold season; whilst the rainiest year, 1878–79, with a rainfall of 35·67 inches, did not experience floods of unusual height, four out of the twelve years showing higher floods; and the highest flood, in March 1876, occurred in a year whose rainfall was only 32·36 inches. The wettest hot season, moreover, of 1878, with a rainfall of 19·64 inches, occasioned less rise in the river in mid-summer than in July-August 1879 with a half-year's rainfall of 15·75 inches. The most rainy of the cold seasons also, (1876–77), with a rainfall of 17·24 inches, did not coincide with a period of greatest floods; for the cold seasons of 1875–76, 1878–79, 1879–80, 1880–81, and 1882–1883 experienced higher floods, with rainfalls respectively of 14·64, 16·02, 9·05, 14·56, and 17·01 inches. The flood of January, 1880, was somewhat anomalous, being caused by the breaking-up of the ice, for it rose with unusual rapidity and was of very short duration, and occurred in an exceptionally dry winter season; whereas in the other two cold seasons of minimum rainfall, 1873–74 and 1881–82, with rainfalls of 6·10 and 8·58 inches respectively, there was an absence of floods. Nevertheless this flood forcibly illustrates the remarkable difference between the influence of summer and winter rains on the flow of the river; for whereas a rainfall of only 9·05 inches, in the winter of 1879–80, was accompanied by a rise of 23·92 feet above the zero of the Mantes gauge, summer rainfalls of 19·64 and 15·75 inches, in 1878 and 1879, only produced rises of 10·07 and 10·03 feet on the same gauge (Plate 1, Fig. 15).

The flow of a river depends upon the proportion of the rainfall which finds its way into the river; and this proportion varies with the nature of the strata of the basin, and the season of the year. The height of a river is influenced by the period occupied by the rainfall in reaching the river, and the time at which the floods of the various tributaries pass down.

The average amount of rainfall over the Seine basin above Paris has been estimated at 20,895 million cubic yards in the summer months, and 15,671 million cubic yards in the winter; whereas the average summer discharge of the Seine at Paris is only 3,605 million cubic yards, or 17 per cent. of the rainfall, and the average winter discharge amounts to 6,696 million cubic yards, or 43 per cent. of the rainfall. Accordingly, although the average summer rainfall, of this portion of the basin, exceeds the winter rainfall by one-third, the average winter discharge of the river at Paris is nearly double the summer discharge, since the percentage of rainfall which reaches the river in

winter, is nearly two and a half times the summer percentage. This percentage of available rainfall, or coefficient of efflux (*coefficient d'écoulement*) as it has been termed, varies at different periods of the same season according to the state of saturation of the soil, and is different for the various strata. Thus the discharge of the Seine at Paris during the great flood of March 1876 gave a coefficient of efflux of 0·45; and the first large flood in the winter of 1882–83 gave a coefficient of 0·31; whilst the second flood gave a coefficient of 0·51, owing to the saturation of the ground by the preceding flood. Again, the coefficient of efflux from the Granite of the Morvan district averages 0·75 throughout the year, falling to 0·44 in the hot season, and attaining 0·98 in the winter. The Lias of Auxois affords an average coefficient of 0·49, being 0·26 in summer and 0·80 in winter; and the impermeable strata of the Upper Oise basin give a mean coefficient of 0·67. The coefficient of efflux from the sands of Fontainebleau is considered to be practically nothing, and it has been estimated at only 0·14 for the permeable tertiary strata of the Eure basin. The rainfall, however, absorbed by these very permeable strata, feeds springs, which replenish the river at a lower part of the basin.

The rain flows off sloping impermeable strata more rapidly than from permeable strata, as well as in a larger proportion. Accordingly impermeable basins produce torrential floods, which appear soon after the rain has fallen, rise rapidly, and pass away also rapidly. The floods from permeable basins rise more slowly, and are much less high, but they continue for a longer period, as may be seen by comparing the Seine at Bray (Plate 1, Figs. 3 and 9) with the Yonne at Sens, and the Marne at St. Dizier (Plate 1, Figs. 4, 10, and 12). The floods of the Seine present a mixed character, owing to the torrential nature of its tributaries the Yonne and the Marne, which, with their high floods, exercise a predominating influence on the floods at Paris. As the torrential floods from the furthest parts of the basin take only three or four days in reaching Paris, whereas the floods of the tranquil affluents only arrive four or five days later, a great flood at Paris is rarely the result of a single fall of rain. Generally a high flood is caused by the arrival of a second flood from the torrential tributaries before the long-continued floods of the gently-flowing tributaries have had time to subside. This effect may be clearly traced in the most recent high floods, namely those of March 1876 (Plate 1, Figs. 3–7), and December–January 1882–83 (Plate 1, Figs. 9–13). All the highest floods, indeed, are produced by this combination of floods of different origin. Only six instances have been re-

corded, since 1732, of floods, due to a single fall of rain, producing a rise at Paris exceeding 13 feet; three of these were consequent on a sudden break-up of the ice, and the other three resulted from a torrential rainfall falling on a saturated soil. The anomalous character of the latest of these floods, in January 1880 (Plate 1, Fig. 15), produced by the breaking-up of the ice in the river, accompanied by a moderate rainfall, has been already alluded to; it rose 15 feet 5 inches in four days, reaching 17·71 feet on the Tournelle Bridge gauge. The preceding instance of a high flood, due to a single rise of the tributaries, occurred at the close of the hot season of 1866, and resulted from a heavy rainfall on a soil completely saturated by almost continuous rains since the middle of July; the river rose 15 feet 1 inch in six days, attaining 17·06 feet on the Tournelle gauge. The rise of the 1879–80 flood is the largest on record at Paris of these peculiar floods; but more rapid rises occurred from the breaking-up of the ice on the 30th–31st of January, 1795, and the 25th–26th of January, 1830, when within a period of two days the river rose 13¾ and 14¾ feet respectively. The greatest actual height of these floods was attained by the flood of February 1784, marking 20·17 feet on the Tournelle gauge; and the flood of January 1830 comes next, with a height of 18·70 feet.

As the flow of the Seine is of a mixed character, in which the gently-flowing streams predominate, very high floods are rare at Paris, as they are only produced by an unusual concurrence of various causes. Mr. Lemoine has divided the floods of the Seine at Paris into three classes, denominating floods which rise between 5 and 6 metres (16·4 to 19·7 feet) on the Tournelle gauge as ordinary large floods, those rising from 6 to 7 metres (19·7 to 23 feet) as extraordinary floods, and those above 7 metres (23 feet) as exceptional floods.[1] During the one hundred and fifty-one years which have elapsed between the establishment of daily readings of the river at Paris in 1732 up to 1883, there have been thirty-one ordinary floods, twelve extraordinary, and two exceptional floods, namely, in December 1740 and in January 1802, when the heights attained were 25·95 feet and 24·37 feet, respectively, on the Tournelle gauge. Mr. Belgrand gives a list of five exceptional floods which occurred between 1649 and 1732, namely, in February 1649, January 1651, February 1658, April 1690, and March 1711, of which that of 1658 alone was higher than the flood of 1740, reaching a height of 28·90 feet, being by nearly 3 feet the highest flood on record at Paris. The four other

[1] "Manuel Hydrologique du Bassin de la Seine." A. de Préaudeau, p. 35.

floods, though lower than the flood of 1740, exceeded the flood of 1802.[1] The flood of 1658 followed on the breaking-up of the ice in the river after a frost which had lasted for five weeks, and was intensified by the thawing of a large quantity of snow accompanied by rain; and the flood of 1740 resulted from prolonged and heavy rains falling upon a large accumulation of melting snow.

From the above records it appears that, whereas four exceptional floods occurred in the latter fifty-one years of the 17th century, only two occurred in the 18th century, and one only has hitherto appeared in the present century. This result indicates, either an inaccuracy in the earlier records, or a freer channel for the flood-waters. Now comparing the floods of the later eighty-three years of the last century with the first eighty-three years of the present century, there have been fifteen ordinary [2] and five extraordinary floods in the former, and twenty-three ordinary and six extraordinary floods in the latter, and one exceptional flood in each. Out of the forty-five large floods recorded since the commencement of the daily observations at the Tournelle gauge in 1732, only three occurred within the warm season, and two of them appeared in May (1779 and 1836), and one in September (1866). This shows that regular floods of the Seine at Paris are almost wholly confined to the cold season; whilst the occurrence of the exceptional instances at the beginning and close of the warm season indicates that they may be traced rather to a slight displacement of the ordinary limits of the cold season than to any peculiar conditions. Two extraordinary floods are, indeed, given by Mr. de Préaudeau, as having taken place in June 1693 and June 1697, the latter reaching the exceptional height of 24·11 feet; but they were ignored by Mr. Belgrand, and throw a doubt on the records of the 17th century.

In the summer season, the rain very seldom rises above 3·50 metres (11·48 feet) on the Tournelle gauge; and Mr. de Préaudeau considers floods rising between 3·50 and 4·50 metres (11·48 to 14·76 feet) as large summer floods, and those exceeding 4·50 metres (14·76 feet) exceptional summer floods. Only ten of these summer floods have been recorded since 1700; and of the four exceptional cases included in this number, one flood does not reach the limit of 5 metres assigned to ordinary large floods. Seven

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[1] "La Seine, Études Hydrologiques." M. Belgrand, p. 300.

[2] The recorded number between 1732 and 1800 is 12, so a proportionate number has been added for the previous years.

of these floods occurred in May, and one in September, thus bordering on the limits of the cold season. Two only occurred in the middle of the hot season; one in June 1757, which rose to 12·96 feet on the Tournelle gauge, and one in July 1816, which only reached 11·78 feet.

Only two unusually high floods have occurred at Paris since 1850, namely, in March 1876, and in January 1883 (Plate 1, Figs. 7 and 13), reaching 21·33 feet and 19·69 feet, respectively, on the Tournelle gauge; though the floods of December 1872 and 1882 were only a little lower, as they rose to 19·19 and 19·16 feet respectively. These two floods, besides being the highest recent floods, possess the special interest of having formed the subject of careful investigations by Messrs. Belgrand and Lemoine,[1] and Messrs. Lemoine and Préaudeau,[2] and of having been the first floods of unusual height to which the system of predictions and warnings was thoroughly and successfully applied. Both floods were due to a succession of floods in the torrential tributaries, the later ones concurring with the floods of the gently-flowing tributaries in raising the water-level at Paris (Plate 1, Figs. 3 to 8, and 9 to 14). The two floods, however, though resulting from a similar combination of causes, like most high floods on the Lower Seine, presented some notable differences. The flood of March 1876 was unusually late in the cold season (Plate 1, Fig. 15), and was produced by an almost continuous rainfall, from the 11th of February to the middle of March, falling upon melting snow at the beginning, and on a soil previously saturated by the winter rains. The river rose almost continuously at Paris from the middle of February till the 17th of March, when it attained its maximum (Plate 1, Fig. 7). The flood of January 1883 was the result of two distinct periods of heavy rainfall following close upon one another, the first extending from the 8th of November to the 9th of December, and the second from the 21st of December 1882 to the 3rd of January 1883. The January flood was accordingly preceded by a high flood in December, which was produced by a greater rainfall than that of February–March 1876, but rose less high at Paris, owing doubtless to the earlier period of the winter season in which it occurred, and to its not being intensified by melting snow (Plate 1, Fig. 13). The January flood was the result of a much smaller rainfall, falling, however, upon an over-saturated soil, and before the previous flood had fully

[1] "Annales des Ponts et Chaussées," 5th series, vol. xiii. p. 435; and also Minutes of Proceedings Inst. C.E. vol. l. p. 221.

[2] "Annales des Ponts et Chaussées," 6th series, vol. vi. p. 314.

subsided. Accordingly the flood of the 5th of January 1883 exceeded that of the 7th of December 1882, though it did not attain the height of the March 1876 flood at Paris, owing to the break in the continuity of the rainfall. The 1883 flood approached nearer to the maximum of the 1876 flood below the confluence of the Oise, owing to the higher flood of that river in 1883; so that at Mantes (Plate 1, Fig. 15), the flood of 1883 was only 3½ inches lower at its maximum than that of 1876. Lower down the river, the flood of December 1882 actually exceeded the 1876 flood between the bridges of St. Pierre du Vauvray and Rouen, for it rose to 39·43 feet and 20·70 feet on the gauges at the Vauvray and Oissel bridges in December 1882, as compared with 39·17 and 19·82 feet, respectively, in March 1876. This peculiar result was due to the maximum in 1882 coinciding with a high tide, which was not the case in 1876; for the tidal influence during a high tide extends above Martot Weir, which is quite open in flood-time.

The maximum discharge of the Seine at Paris during the flood of March 1876 amounted to 2,171 cubic yards per second, or about forty-seven times its minimum discharge of 46 cubic yards. The maximum discharge of the flood of January 1883 at Paris was 1,967 cubic yards. The discharge at Mantes, during the height of the flood of March 1876, was calculated at 2,943 cubic yards, the minimum summer discharge of the river at that place being about 85 cubic yards per second; whilst at the lock of Meulan, a little above Mantes, the maximum discharge on the 9th of December 1882 was found to be 2,914 cubic yards. The greatest discharge measured on the river during the latter flood was below Elbeuf, beyond the confluence of the Eure, on the 11th of December 1882, and amounted to 3,248 cubic yards per second.

The areas of land inundated between Paris and Rouen were nearly the same in the floods of 1876 and 1882–3, amounting in 1876 to 29,557 acres, and in 1882–3 to 31,371 acres. The flood of 1876 extended over a width of 4 miles in some places, as for instance at Poses. There are only four districts where the land is protected against floods by embankments, so that, for the most part, the floods flow freely over the adjacent meadows. The Venables embankment was breached by the flood of 1876, which increased the inundated area at that part; but though no embankment failed during the flood of 1882-3, the higher rise in the lower part of the river, alluded to above, caused the inundation produced by the latter flood to exceed even that of 1876.

The velocity of propagation of the maximum of a flood differs according to the nature of the flow of the river, being much

quicker on torrential rivers. It varies also in a river of mixed characteristics like the Seine at different places, and even in different floods according to the changes in the preponderating influences of the various tributaries. Thus the velocity of propagation below Paris, which varied during the flood of 1876 between 1·4 mile per hour at Oissel and 1·9 mile at Garenne, averaging 1·86 mile per hour, amounted to 2·86 miles between Paris and Mantes during the flood of December 1882 owing to the greater influence of the Oise, but was only 1·3 mile per hour in the flood of January 1883; whereas, on the Upper Seine, the velocity averaged 5·72 miles in December 1882, and 3·73 miles in January 1883 between Montereau and Paris. The maximum flood-level took from four and a half to five days in travelling from Clamecy, near the extreme limit of the Yonne basin, down to Mantes, a distance of 238 miles; and four days are generally considered available for predictions of a flood-rise at Mantes.

## Predictions of Floods.

The system of predicting the probable height of floods, at certain places on a river, from the indications furnished by the heights attained in the upper tributaries, was inaugurated by Mr. Belgrand for the Lower Seine in 1854. By a series of careful observations, he was enabled to trace a relation between the rise of the various tributaries, at certain points, and the corresponding rise of the Seine at Paris, or lower down. The usual rule adopted for calculating the probable flood-rise of the river at the bridge of Austerlitz at Paris is to double the mean of the rises observed on the Yonne at Clamecy, the Cousin at Avallon, the Armançon at Aisy, the Marne at Chaumont and St. Dizier, the Aisne at St. Menehould, the Aire at Vraincourt, and the Saulx at Vitry le Brûlé. When the rise is preceded by a fall, the mean rise must be multiplied by 1·55; but the results are less exact than in the first case. Another rule is to substitute the Grand Morin at Pommeuse for the Aisne and the Saulx in the above list, which is useful in introducing the influence of the torrential Grand Morin, which exercises a marked effect on small floods, though the small extent of its basin prevents its influence being much felt in high floods. The mean time occupied by the maximum flood-level in travelling from the upper affluents to Paris is three days and four-tenths, and one day from Paris to Mantes. The rise at Mantes is generally the same as at Paris; but when the predicted rise of the Oise at Venette exceeds that of the Seine at Paris, about 1 foot must

be added for the rise at Mantes. The announcements are generally made three days in advance, and a corrected prediction is issued twenty-four hours later. The heights predicted are usually somewhat in excess of the actual heights recorded, owing to the natural anxiety not to give too low an estimate of the flood; but the discrepancies will tend to diminish with extended experience. Some remarkable coincidences occurred during the two largest recent floods between the predicted and the observed heights of the river. Thus, the height predicted on the 15th of March 1876 for the following day, of 21·33 feet on the Austerlitz gauge, was exactly verified; and the prediction on the 14th of March for the 17th, of 21·98 feet on the same gauge, was recorded at 21·91 feet in the evening of the 17th. On the 26th of November 1882, the probable height of the river on the Mantes gauge was given as 25·26 feet, and the recorded height on the 8th of December was 24·74 feet; and the height predicted on the 5th of January 1883 was 25·26 feet, whilst the height attained on the 7th was 24·93 feet. At Paris, the exact maximum of the flood of January 1883 was predicted the previous evening.

The same system of predictions was established by Messrs. Belgrand and Lemoine for the Aisne, the Oise, the Marne, and the Upper Seine in 1872; but it could not be applied to the higher portions of these rivers, except by means of deductions from the rainfall returns which would furnish somewhat uncertain indications; and, moreover, the warning could only be given so short a time before the arrival of the flood as to be practically useless. Though warnings of approaching floods were principally intended for the benefit of navigation and river-works, they have proved very valuable for the riparian proprietors, who, on the occurrence of the great floods of 1876 and 1882–3, received sufficient notice to enable them to remove their labourers and goods to places of safety, and to raise embankments threatened with submersion.

No extensive works have been undertaken for preserving the valley of the Seine from inundations; but Paris has been protected by raising the quays along the river, and by prolonging the outfall sewers so as to place their outlets beyond the town; and four low-lying districts below Paris have been sheltered by embankments. The rebuilding also of old bridges with more ample waterways, and the improvements in depth for navigation, have increased the discharging capacity of the river. The recurrence, however, of an exceptionally high flood like that of 1658, or even of 1740, would expose portions of Paris to inundation; whilst one of the protected districts was flooded in 1876.

The floods of the Lower Seine flow so gently over the adjacent lands that they cause little injury; whilst the inundations of the Upper Seine serve as reservoirs for preventing a too rapid descent of the flood-waters on to Paris.

The universal adoption of movable weirs throughout the Seine basin enables the flow of the river to be left unimpeded during winter floods; and the warnings sent to the weir-keepers of the approach of a sudden flood secure its rapid passage through the weirs, without the chance of unduly lowering the water for navigation.

## II. INLAND NAVIGATION IMPROVEMENT-WORKS.

The Seine is an extremely winding river, which greatly increases the distance by water between the towns along its banks (Plate 2, Fig. 1). Thus the distance between Montereau and Paris is 42 miles in a straight line, and 60 miles by the river; between Paris and Rouen, 70 miles in a straight line, and 150 miles by the river; and 45 miles from Rouen to the sea in a straight line, and 80 miles by the river and estuary. This large augmentation in the actual length to be traversed, however, though placing the inland navigation at a disadvantage in this respect as compared with railways, has the effect of reducing the fall of the river, which makes the river more stable, reduces the velocity of the current, and renders the canalization of the river easier. The total fall of the bed of the river is about 74 feet between Montereau and Paris (Tournelle Bridge), a distance of 61 miles, and about 76 feet between Paris and St. Aubin, a distance of 135 miles; so the average fall between Montereau and Paris amounts to $14\frac{1}{2}$ inches per mile, whilst between Paris and St Aubin it is only $6\frac{3}{4}$ inches per mile. The fall and the depth vary considerably at different parts, but are more irregular below Paris than above (Plate 2, Figs. 2 and 3).

Like most rivers, the Seine in its natural state consisted of a series of shallows and pools, causing irregularities in the current, which are always unfavourable to the up-stream navigation; whilst in times of drought shoals barred the passage. The only improvements effected on the Lower Seine, before the present century, consisted in narrowing the channel at certain places, called passes, so as to retain a greater depth of water over shoals higher up. The increased current, however, through these passes hindered the up-stream navigation; and forty horses were required for drawing a boat through the old pass of Morue, near Bezons.

## Lower Seine Navigation Works.

The first distinct work of river improvement on the Lower Seine consisted in forming a side channel with a lock at Pont de l'Arche, where the old bridge acted like a weir. This work was commenced in 1804, and completed in 1813. Between 1813 and 1838, the river-works were confined to the improvement and raising of the towing-paths, and dredging shoals. As all the vessels at that time were towed up-stream by horses, great benefit was derived from an improved towing-path; but the removal of shoals proved of little practical advantage, for though the current was thereby rendered more uniform, its velocity was increased, and as the river was lowered fresh shoals appeared. At length, in 1838, the regular canalization of the river was undertaken between Paris and St. Aubin. Mr. Poirée had already successfully tested his system of needle-weirs within the Seine basin by erecting needle-weirs across the Yonne, at Basseville, in 1834, and at Épineau in 1838, for providing an intermittent navigation by means of flushing on that river. He accordingly designed similar weirs, with adjacent locks, for canalizing the Lower Seine, and securing a depth of 5¼ feet. Seven weirs, with their accompanying locks, were erected between 1838 and 1866,[1] dividing the Lower Seine into seven reaches, namely, St. Aubin-Poses, 9¼ miles in length; Poses-Garenne, 25½ miles; Garenne-Meulan, 41¼ miles; Meulan-Carrières, 12½ miles; Carrières-Bougival, 16½ miles; Bougival-Suresnes, 19½ miles; and Suresnes to the Tournelle Bridge, 10½ miles long (Plate 2, Figs. 1 and 2). The river has a width of from 400 to 600 feet between Paris and Épinay; 500 to 750 feet between Épinay and Meulan; and 550 to 980 feet between Meulan and Rouen: and it is subdivided for considerable distances into two or more channels by numerous long islands. Advantage was taken in every instance of these islands for placing the locks and weirs in separate channels, sometimes at points on the river a considerable distance apart, as for instance in the case of Bezons weir and Bougival-lock, which are as much as 5½ miles from each other. Mr. Krantz, when proposing fresh works in 1871, stated that the great differences in the lengths of the reaches on such a regular river as the Seine

[1] Bezons weir, with a lock at Bougival, was commenced in 1838; Andrésy weir, with a lock at Carrières-sous-Poissy, in 1846; Notre Dame de l'Isle weir, with a lock at Notre Dame de la Garenne, in 1849; Poses weir and lock in 1850; Meulan weir and lock in 1853; Martot weir with St. Aubin lock in 1862; and Suresnes weir and lock in 1866.

constituted a notable defect in the above works.[1] From an inspection, however, of the longitudinal section of the river below Paris (Plate 2, Fig. 2), it does not appear that the arrangement of the sites of the locks is open to objection, with the exception of the great gap left between the Garenne and Meulan locks, where the canalization was imperfect, forming an impediment to navigation in dry seasons.

On the completion of Mr. Poirée's navigation-works, it was found that they did not secure, in times of drought, the anticipated navigable depth of 5½ feet, mainly because, in estimating the available depth in the upper portion of the reaches, credit was given for the inclination of water-level due to the ordinary fall of the river between the weirs; whereas, after a succession of very dry seasons, the discharge of the river fell below its normal amount, and the water-surface became nearly level. This loss of depth was naturally more marked at the upper parts of the reaches; but it must be attributed rather to the error in taking credit for an inclination of water-surface which might cease to exist, than to the unequal distribution of the weirs.

In 1866 fresh works were determined upon, not merely to remedy the deficiencies of the previous works, but also to increase the navigable depth to 6½ feet.[2] These works consisted of an additional lock and weir at Port Villez for improving the depth in the long Garenne-Meulan reach, and the repair and raising of the weirs and locks at Poses, Garenne, and Meulan. Before these works, however, were completed, the need of a still more comprehensive scheme was recognized for providing a greater navigable depth between Paris and Rouen. The completion, however, of the works in progress, and the consideration of extended works, were delayed by the war of 1870–71. At length in 1878 fresh works were authorized, with the object of increasing the depth of the Seine between Paris and Rouen to 10½ feet, so as to secure a navigable channel for vessels of 800 to 1,000 tons burden, drawing 9 feet 10 inches of water. These works consisted in heightening or altering the existing weirs, so as to raise the water-level in the reaches; building larger and deeper locks; erecting a new weir and lock at Méricourt, between Port Villez and Meulan; and

[1] "Amélioration de la Navigation de la Seine entre Paris et Rouen," J. B. Krantz, pp. 12 and 13.

[2] Mr. Poirée's scheme of 1845 was intended to provide a navigable depth of 6½ feet between Paris and Rouen by means of fourteen locks and weirs; but a depth of 5½ feet was considered adequate at that time, and the scheme was modified accordingly.

dredging at certain shoal places. The condition of the Lower Seine when all these works shall have been fully completed is shown on the section (Plate 2, Fig. 2). The river is divided into nine reaches, in which the depth is reckoned on the assumption that the water may at times stand perfectly level, so that the chance of an insufficiency of depth, owing to the absence of fall in a dry season, is eliminated; and the only possibility of a reduction in depth below the assigned limit of 10½ feet would be if the loss of water by leakage, evaporation, and lockage, should ever in time of drought exceed the discharge. The falls at the locks are various, ranging between 5¾ feet at Meulan and 13¾ feet at Poses, whilst the average is 9½ feet; the total difference in level between the water-level of the Paris reach, and high water of ordinary neap-tides at St. Aubin, being 85 feet.

On the completion of the above works, the Seine will afford a very commodious waterway for inland-navigation up to Paris. Large sea-going vessels get up to Rouen, which forms the terminus of an important inland trade by water with Paris and other parts of the country. A navigable channel, however, between Rouen and Paris, 10½ feet deep, does not satisfy every aspiration; and the idea of making Paris itself a seaport, which was first conceived in 1825, has been again revived. It is suggested that a tidal channel, with a minimum navigable depth of 19⅝ feet, should be excavated along the river up to Poissy, 12½ miles from Paris, where a port would be created, and from whence vessels would be enabled, if necessary, to rise through a chain of locks to a higher reach and proceed right up to Paris.[1] The comparatively small difference of about 50 feet in level between Rouen and the environs of Paris has led to the conception of such an apparently bold proposition, similar to the scheme designed by Mr. Fulton for a tidal ship-canal up to Manchester, but much greater in length, though less in maximum depth. The cost of the scheme has been estimated at £10,240,000. The government has not shown hitherto any disposition to further this scheme; and the Rouen authorities are naturally very strongly opposed to it. It would be wise to wait and see whether the greatly improved waterway between Rouen and Paris, now approaching completion, will not suffice to supply all the requirements of Paris, before attempting to burden the State, already

[1] "Résumé d'une Étude sur la création d'un Port de Mer à Paris." M. Bouquet de la Grye, 1882.

Association Française pour l'Avancement des Sciences, 12e Session, Rouen, 1883, pp. 227 and 230.

deeply involved in several costly public works, with an enterprise of which the financial advantage is problematical. Rouen appears to be the natural limit of maritime trade on the Seine (Plate 2, Fig. 2); and the improvement of the estuary channel between Berville and Havre (Plate 4, Figs. 1 and 2) is of far more pressing importance than the extension of the tidal river up to a point which, whilst involving a large expenditure and altering greatly the water-levels in the upper valley of the Lower Seine, would not actually attain to Paris.

## Upper Seine Navigation-Works.

The improvement of the Seine for navigation between Montereau and Paris, by means of locks and weirs, was only undertaken in 1860, when the treaty of commerce gave an impulse to the methods of communication throughout France. Previously the Upper Seine was quite open; and the only aids to navigation were the flashes coming down from the Yonne and Little Seine, which created a temporary flood, and augmented the depth whilst they lasted. These flashes were produced on the Yonne by rapidly opening the needle-weirs placed right across the river, of which the earliest was erected in 1834; but the small artificial flood produced by them only lasted about twelve hours in the Upper Seine, and only increased the depth from a maximum of 2¼ feet at Montereau to 1 foot near Paris. In 1846 it was decided to erect weirs between Nogent and Montereau, so as to provide a similar system of flashes on the Little Seine, which, combined with the flashes of the Yonne, would increase the duration and height of the flood on the Upper Seine. In 1859, it was even proposed to extend the formation of the flashes to the Upper Seine itself by the erection of three movable weirs between Paris and Montereau; but this plan was superseded in 1860 by the decision to abandon the system of intermittent navigation, so prejudicial to the passage of vessels up-stream.

The scheme of 1860 consisted in the canalization of the Upper Seine by the erection of twelve weirs and locks, arranged so as to secure a navigable depth of at least 5¼ feet over the lower sills of the locks, with the water standing level in the reach below. The weirs were necessarily placed much closer together than on the Lower Seine, owing to the greater natural inclination in the bed of the river above Paris; and they were so spaced that each weir kept up the water 7 feet 10½ inches above the summer level at its site. Mr. Chanoine, who had charge of the works, designed a

system of movable shutters for closing the weirs, instead of the needle-weirs erected by Mr. Poirée on the Lower Seine (Plate 3, Fig. 8). In 1878 it was decided to increase the navigable depth from 5¼ to 6½ feet. This improvement has been effected by deepening the two top reaches, and lowering the sills of the lock at Varennes, and by raising the water-level in the other ten reaches, which necessitated the reconstruction of the movable portions of the weirs (Plate 3, Figs. 8 and 9). The present condition of this section of the river is shown on Plate 2, Fig. 3. The reaches vary in length from 2⅝ miles between Courbeton and Varennes, to 7 miles between Évry and Ablon; and the falls at the weirs vary between 4½ feet at Vives Eaux, and 8¾ feet at Port-à-l'Anglais, and average 5·6 feet. The change effected by the canalization is readily perceived by contrasting the present summer state of the river, when the water is level in the reaches, with the summer water-level of 1840, when the river was in its natural condition (Plate 2, Fig. 3).

The Oise, the Marne, the Yonne, and other tributaries of the Seine, have been rendered navigable by means of locks and weirs; and canals have been constructed to extend these inland navigations, and to connect them with the waterways of the adjacent basins. The length of navigable waterways within the Seine basin amounted in 1872, according to Mr. Krantz, to 1,585 miles; but he considered that several connecting links within the basin were needed, and also the junction of the Marne and the Saône by means of a canal.

## Weirs.

All the weirs on the Seine belong to the general class of movable weirs, though they present various differences in design. In fact, examples of all the principal types of movable weirs are to be found in the Seine basin. The needle-weir[1] was for a long time the sole type adopted on the Lower Seine; whilst only shutter-weirs[2] were erected on the Upper Seine. Drum-weirs[3] have been confined exclusively to the Marne; and the only examples of the bear-trap-weir,[4] the hydraulic shutter-weir,[5] and the segmental gate-weir,[6] are at La Neuville on the Marne, at Brulée Island on the Yonne,

[1] "Rivers and Canals." L. F. Vernon-Harcourt. Plate 5, Fig. 3.
[2] "Fixed and Movable Weirs." Minutes of Proceedings Inst. C.E., vol. lx., Plate 2, Fig. 4, and Plate 3, Figs. 1 and 2.
[3] *Ibid.*, Plate 3, Figs. 3 and 4. [4] *Ibid.*, Plate 2, Fig. 1. [5] *Ibid.*, Plate 2, Fig. 2.
[6] "Rivers and Canals." L. F. Vernon-Harconrt. Plate 6, Figs. 4, 5, and 6.

and at La Monnaie in Paris, respectively. The largest ordinary frame-weir in France has been erected at Port Villez, on the Lower Seine (Plate 3, Figs. 5 and 6); whilst the first suspended frame-weir has been recently (September 17th, 1885) completed across the Seine at Poses (Plate 3, Figs. 3 and 4). The variety of types adopted within one river-basin has been due to the desire of the engineers in charge of the different sections to devise some new and improved type, and not to the special adaptability of each type to the localities in which they are situated. Thus Mr. Poirée erected needle-weirs on the Lower Seine and the Yonne; Mr. Chanoine placed shutter weirs across the Upper Seine; Mr. Desfontaines employed drum-weirs on the overfalls of the Marne; and Mr. Caméré is occupied in the construction of frame-weirs, suspended from overhead girders, for the new weirs on the Lower Seine.

The different kinds of movable weirs have been so fully described in the Author's Paper on "Fixed and Movable Weirs," read before this Institution in 1880,[1] that a brief description will suffice of the general arrangement of the Seine weirs, together with some account of the modifications and improvements recently effected.

*Upper Seine Weirs.*—The weirs on the Seine are always composed of two distinct sections; namely, a navigable pass, used by vessels when the river is high and the lock is submerged; and a regulating weir with a sill raised above the river-bed, which, having consequently a less height, can be more readily opened for the passage of a moderate flood, and is more convenient for regulating the discharge than the larger weir of the navigable pass.

On the Upper Seine, the navigable pass is placed between the lock, situated alongside the towing-path bank, and the regulating weir stretching from the river pier of the navigable pass to the opposite bank, as shown by the plan of Ablon weir (Plate 2, Fig. 7). The navigable passes on the Upper Seine vary in width from 132½ feet at Varennes and La Madeleine, to 213½ feet at La Cave, and their average width is 165 feet; whilst the regulating weirs vary from 124 feet at Melun, to 230 feet at the four lowest weirs. The sills of the passes are 3¼ feet lower than the sills of the regulating weirs; and formerly both the passes and overfalls were closed by Chanoine's shutters.

In the recent improvement works, higher shutters have been placed on the old sills of the navigable passes, at the lower end of those reaches whose water-level had to be raised 1⅓ foot.

[1] Minutes of Proceedings Inst. C.E., vol. lx. p. 24.

These shutters resemble in principle the shutters they have replaced, but they have been improved in certain details (Plate 3, Fig. 8). The old shutters were liable to be fractured by the shock of their fall on being lowered; they were only raised to within 3 inches of the proper upper water-level, so that special contrivances were required to retain the full height of water in times of drought; a space of 4 inches was left between the shutters; and the shutters, having their axis of rotation situated one-twelfth of their height below the centre, opened of their own accord when the upper water-level rose from 4 to 8 inches above them, and when the tail water was 6½ feet deep, which often happened in rainy years. The new shutters have been made stronger; their crest rises to the proper water-level, 11 feet 2 inches above the bottom, their length on the slant being 11 feet 8 inches; their width has been increased to 4 feet 1 inch, reducing the interval between each shutter to 2 inches; and the axis of rotation has been placed only 1⅓ inch below the centre, which secures the shutter from opening spontaneously. Moreover, a butterfly valve, 3¼ feet high and 2 feet wide, has been placed in the upper leaf of each shutter, which serves to regulate the water-level, to aid the passage of small floods, to ensure the safety of the shutters during larger floods, and to facilitate the raising of the shutters.[1]

The shutters across the regulating weirs have been only retained where the water-level had not to be raised. In all other cases the shutters have been replaced by needle-weirs (Plate 3, Fig. 9). The needles, 11½ feet long and 3 inches square, have been furnished with hooks, so that they can revolve on the top front bar of the foot-bridge, which greatly facilitates their working.[2]

Needle and shutter weirs are accordingly now found side by side on the Upper Seine, and both appear well adapted for a river with a fairly regular flow. Needles are simpler in construction, more easily moved, and less liable to get out of order than shutters; but they require the constant attention of the weir-keeper for regulating the flow. Shutters allow of a moderate flood passing over their crest, and their extent of opening can be adjusted beforehand by their chains. The new weirs on the Upper Seine constitute a notable advance in the facility, rapidity, and security of working of these types of weirs.

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[1] Details of these recent improvements will be found in "Annales des Ponts et Chaussées," 6th series, vol. v. p. 622, and plate 16.

[2] A description of this contrivance is given in "Annales des Ponts et Chaussées," 6th series, vol. ii. p. 220; and in abstract in "Minutes of Proceedings Inst. C.E.," vol. lxvii. p. 453.

*Suresnes Weir.*—The weir at Suresnes, a short distance below Paris, which formerly was a needle-weir precisely similar in construction to Martot weir,[1] has been entirely reconstructed, in order to provide a minimum depth of 10½ feet as far up as Bercy by raising the water-level 3¼ feet. Formerly there was a weir adjoining the lock, another weir opposite Neuilly connecting Rothschild Island with another island in mid-stream, and a third weir between this island and the left bank at Levallois, 2½ miles below the lock. The great distance between the weirs was very inconvenient for working, and the raising of the water-level would have occasioned infiltrations through this long length of narrow islands. Accordingly the weirs have been all placed close to the lock, across the three channels formed by Rothschild Island and the small Folie Island, as shown on Plate 2, Fig. 5. The system of frames has been retained on an enlarged scale, the frames across the navigable pass being about 20 feet high (Plate 3, Fig. 2), in place of 11 feet as at Martot. The system of needles has, however, been abandoned, as the needles requisite for such a height would be too heavy to be moved conveniently: the central regulating weir is closed by sliding panels, as designed by Mr. Boulé, and previously adopted at the Mulatière weir at Lyons, and at six weirs on the river Moskwa; whilst the two side-passes are closed by Mr. Caméré's hinged curtains, first adapted by him to the Port Villez weir (Plate 3, Figs. 5, 6, and 7). These two systems of closing large frame-weirs are accordingly being tested side by side at Suresnes. The sliding panels are cheaper and simpler in construction, and they let the water fall over the top, the upper ones being raised first. The hinged curtain, being rolled up from the bottom, makes the water escape below; it admits of a better adjustment of the discharge through the weir, and is not liable to be impeded by floods in the act of raising. The sliding-panel, being submerged, is less easily worked, but the hinged curtain causes scour at the bottom; the one system has the merit of simplicity and economy, the other possesses the advantage of more regular working. Time will demonstrate their relative durability, and whether the cheapness of the one more than compensates for the efficiency of the other.

The works at Suresnes were completed towards the close of 1884. Mr. Boulé, the Engineer-in-Chief of the works, thinks that a navigable depth of 14¾ feet, instead of 10½ feet, could have been realized with a not much greater expenditure of time and money;

[1] A section of Martot weir is given in "Rivers and Canals," Plate 5, Fig. 3.

and he considers it possible that these new works may not exceed in duration the works of 1866–67, which they have replaced, in view of the prospect of extended improvements in weirs and increased requirements for navigation.

*Port Villez Weir.*—The weir at Port Villez, near Vernon, unlike the older weirs on the Lower Seine, has been carried across the river where it is quite clear of islands, so that the weir forms a continuous line from the lock on the left bank over to the right bank. The total length of the weir is 700 feet. The weir consists of two central navigable passes, and a regulating weir on the right side of the river, which are separated by two intermediate piers (Plate 3, Fig. 5). The sills of the navigable passes are situated 13 feet 1½ inch below the upper water-level, and the sill of the regulating weir is only half that depth down. The weir is closed by frames of the Poirée type, supporting a series of Mr. Caméré's hinged curtains (Plate 3, Figs. 5, 6, and 7). The frames are placed 3 feet 7½ inches apart; those across the navigable passes are 18 feet high, and weigh 37½ cwts., and those on the overfall are 9 feet 2 inches high, and weigh 7½ cwts. The tops of all the frames are 1⅔ foot above the upper water-level, and carry a foot-bridge and a small tramroad, upon which the carriages for conveying the curtains run (Plate 3, Fig. 7). The weir cost £163 7*s.* per lineal foot. Works were begun in 1869 with a view to the erection of a pontoon-weir, according to a novel design by Mr. Krantz;[1] but a trial made of the system at Bougival having proved unsatisfactory, the design was abandoned, and the frame-weir eventually adopted was commenced in 1876. Since its completion in June 1880, it has satisfactorily fulfilled all the requirements as regards navigation. The curtains are worked with ease, and have proved both watertight and durable. The frames have not proved equally satisfactory, for, owing to their great height and weight, and the silting up of their resting-place in the river-bed, they are liable to be deflected, and even to be broken when lowered. The introduction, however, of a curve in the surface of the apron just above the weir (Plate 3, Fig. 6) keeps the floor of the frames clearer of silt, and has consequently reduced the chance of injury. Each frame can be raised or lowered in ten minutes; and the same time is occupied in rolling up or unrolling a curtain; whilst six minutes and two-thirds, on the average, suffice for conveying a curtain to its destination. The whole operation of opening or closing the weir completely occupies two and a half days, when a gang of four men is em-

[1] Minutes of Proceedings Inst. C.E., vol. lx. p. 38, and Plate 3, Figs. 5 and 6.

ployed at the frames and another similar gang at the curtains, during the daytime only. This rate of work suffices for the Seine, but it evidently could be readily accelerated by working at night, or by employing more gangs.

*Poses Weir.*—Formerly the weirs of Poses were situated about ½ mile apart, and more than a mile above the lock. The new weir has been erected across a wide branch of the river close to the locks, and only separated from them by the narrow end of an island (Plate 2, Fig. 4). This weir has been constructed on an entirely novel principle; for though a system of lifted frames was suggested in 1873 by Mr. Tavernier for the Saône, Poses weir, designed by Mr. Caméré, is the first instance in which all the movable parts of a weir can be removed completely from the river-bed. The weir is of the frame type, and is closed with hinged curtains, like that at Port Villez; but the frames, instead of being fastened on to the apron and lowered on to the river-bed in flood-time, are suspended from an overhead girder, and, whilst their ends rest against the sill of the weir, when hanging vertically in place, they can be raised in flood-time to a horizontal position entirely out of the river (Plate 3, Fig. 3). This arrangement secures the frames from any chance of injury when the weir is open, and it greatly facilitates the working and maintenance of the frames. It, however, necessitates the adoption of long frames for the navigable passes, so that the frames when raised may afford a sufficient headway underneath for the passage of vessels in flood-time, and also overhead girders resting on high piers for supporting and lifting the frames. The great increase entailed thereby in the size of the works is most forcibly illustrated by Plate 3, on which the different types of weirs have been drawn to the same scale for the sake of comparison. Even Suresnes and Port Villez weirs, and the shutter-weirs of the Upper Seine (Plate 3, Figs. 2, 6, and 8), though the largest weirs of their class, sink into insignificance when compared with the hinged frame-weirs of Port-Mort and Poses (Plate 3, Figs. 1 and 3).

The weir at Poses consists of seven openings separated by piers (Plate 2, Fig. 4), of which the two adjoining the left bank are navigable passes, 106½ feet wide, with sills 16 feet 5 inches below the upper water-level, and leaving a clear headway of 17¼ feet above the highest navigable flood-level, 1⅓ foot higher than the ordinary level, but 3⅛ feet below the flood of 1876 (Plate 3, Figs. 3, and 4). The three passes nearest the island are each 99 feet in width, and have their sills at the same level as the navigable passes; but their overhead girders are placed 8 feet lower in level

than those of the navigable passes. The two central openings are also 99 feet wide, and have their girders at the same level; but their sills are 6⅔ feet higher than the rest of the weir (Plate 3, Fig. 4). There is a foot-bridge across the weir, and the levels of the girders are so arranged that the platform between the girders over the navigable passes is level with the platform on the top of the girders across the other passes, so that the roadway of the bridge is at a uniform level throughout. Four verticals are braced together so as to form a single frame occupying 7 feet 7½ inches in width of the weir. A hinged plate at the back of each frame provides a small foot-bridge at the back of the weir, above the highest navigable flood-level, from which the curtains are rolled up or unrolled by aid of a crab (Plate 3, Fig. 3). The curtains are precisely similar in design to those of Port Villez, but they have been doubled in width, being 7½ feet wide, with a clearance of 1½ inch between them. The curtains are not removed when rolled up for opening the weir, but they remain on the frame whilst it is being raised by chains from the bridge, and even after it has reached its horizontal position, unless needing repairs (Plate 3, Figs. 1 and 3). The rolling up or unrolling of a curtain of one of the deep passes occupies fifteen minutes; whilst the raising of a frame occupies twenty minutes, and its lowering ten minutes. Consequently one of the passes could be entirely opened in five hours; and the whole weir would require from five to thirty-five hours for opening, according to the number of gangs employed.

The weir was put into operation in September 1885. It cost £151 5*s.* per lineal foot, being less than that at Port Villez, notwithstanding the overhead girders, high piers, and long frames, as well as the greater head of water retained. The smaller cost of an apparently much larger work must be partly due to the less strength required for the frames, which are only exposed to the direct pressure of the water when the weir is closed, to the simpler apron in the absence of hinges at the bottom for the frames, and to the saving of the cost of modifications in the foundations and frames, and of experiments on the novel system of curtains, which were carried out at Port Villez weir. As the only objection that could be raised against the Poses type of weir would be the cost of so large a work, it is evident that if the expenditure on Poses and Port Villez weirs may be accepted as a fair comparison of the respective cost of the two systems, the suspended frame-weir is decidedly superior to the ordinary frame-

weir for heads of 10 feet and upwards. For whilst the suspended frame-weir is apparently not more costly than the ordinary frame-weir in these cases, it is more quickly raised or lowered, and more easily maintained. Moreover, this system provides a permanent foot-bridge, and it could readily be adapted for greater heights by merely having longer frames and higher piers.

*Port-Mort Weir.*—The intervening weir between Port Villez and Poses was formerly situated across the right branch of the Seine, at Notre Dame de l'Isle, about 2 miles above the lock of Notre Dame de la Garenne. The site of the weir has been changed, like at Suresnes and Poses, so as to place it near the lock; and the new weir is being constructed across the right branch of the river, in a line with the old needle-weir adjoining the lock (Plate 2, Fig. 6). The needle-weir has simply been heightened, so as to retain a raised water-level of $1\frac{1}{2}$ foot. The new weir in course of construction consists of seven passes, each about 99 feet wide, separated by piers 13 feet in width, and having sills 13 feet 1 inch below the upper water-level. It is very similar in design to Poses weir, differing only from it in a few minor details (Plate 3, Fig. 1). The verticals are braced together in pairs, each frame being separated by an interval nearly equal to its width, so that each curtain, having the same width as at Poses, will overlap its frame on each side, and meet the adjacent curtains in the centre of the intervals between the frames. The overhead girders are all placed at the same level, so that when the frames are raised there is a clear headway of $16\frac{1}{4}$ feet above the highest navigable level, as at the navigable passes at Poses. Owing, however, to the much greater height of the navigable level above the normal level, the frames have to be longer, and the piers higher than at Poses, though the normal head is $4\frac{1}{3}$ feet less. (Compare Plate 3, Fig. 1 with Fig. 3.) The difference between the upper and lower water-levels is less at Port-Mort than at Suresnes and Port Villez, or even than at the Upper Seine weirs, so probably a cheaper form of weir might have been adopted in this instance.

*Meulan and Méricourt Weirs.*—The improvement-works comprise the reconstruction of Meulan weir, and the construction of an additional weir at Méricourt between Meulan and Port Villez.

Meulan weir is situated where the river is separated into two channels by an island; and the new weir is designed to have two navigable passes, having a total width of 243 feet, and a shallow pass, 115 feet wide, across the left branch of the river and adjoining the locks on the left bank; whilst another weir stretches in the same line across the right branch, having a width of 256 feet.

Méricourt weir, in course of construction, extends in an unbroken line from the locks on the left bank to the opposite bank. It consists of two navigable passes adjoining the lock, having a total width of 213 feet, and two shallower passes with a total width of 485 feet.

The navigable passes of both these weirs are to be closed by suspended frames supporting hinged curtains, resembling Port-Mort weir; whilst the other portions of the weirs will have ordinary frames with curtains, like Port Villez weir.

*Bezons, Andrésy, and Martot Weirs.*—The two weirs between Suresnes and Meulan, at Bezons and Andrésy, and the lowest weir on the Seine at Martot, require so little modification to provide the increased depth, that it is not proposed to change their sites, although Martot weir is $\frac{1}{2}$ mile away from St. Aubin lock, and Bezons and Andrésy weirs are a considerable distance from their corresponding locks, at Bougival and Carrières-sous-Poissy (Plate 2, Fig. 1). As the water-level of the Bougival-Suresnes reach is to remain unaltered, no raising of the needle-weir at Bezons is necessary; but it is proposed at some future time to lower the sill of the navigable pass $3\frac{1}{4}$ feet, so that it may be 13 feet below the upper water-level.

The water-level of the Carrières-Bougival reach has been raised 10 inches by lengthening the needles of Andrésy weir and raising the foot-bridge on the frames $1\frac{1}{2}$ foot. The sills of the navigable passes are eventually to be lowered $2\frac{1}{8}$ feet, so as to obtain a depth of 13 feet over them.

Since the water-level of the St. Aubin-Poses reach is not to be altered, the needle-weir at Martot will need no modification, except at the navigable pass, when the proposed lowering of its sill $3\frac{1}{3}$ feet is carried out.

## Locks.

*Upper Seine Locks.*—The twelve locks on the Upper Seine adjoin the weirs (Plate 2, Figs. 3 and 7). Eleven of these locks have pitched slopes of 1 to 1 at the sides; they are $55\frac{3}{4}$ feet wide at the surface-level of the lower pool, which is $6\frac{1}{2}$ feet above the bottom, and the available length of the lock-chamber is 564 feet. The lock at Port-à-l'Anglais, just above Paris, has vertical side-walls; its chamber has an available length of 590 feet, and a width of $52\frac{1}{2}$ feet. The entrance width of these locks is $39\frac{1}{3}$ feet.

*Lower Seine Locks.*—Previous to the commencement of the works, authorized in 1878, for increasing the depth of the Lower Seine to

10½ feet, there were single locks at each of the weirs, with lock-chambers about 394 feet long and 39½ feet wide. At Bougival, where the traffic is the greatest, the old lock has an intermediate pair of gates. The new works comprised the construction of enlarged locks, with their lower sills 10½ feet below the water-level of the lower pools, supplemented in most instances by a smaller lock alongside, to prevent unnecessary waste of water in locking smaller vessels. The lock-chambers of the large locks are 462 feet long and 55¾ feet wide, and of the small locks 197 feet long and 27 feet wide. The available entrance width, however, at the gates of the large locks is retained at 39½ feet, as in the old locks. The lock-chambers at Suresnes (Plate 2, Fig. 5), and Bougival have been given the greater lengths of 526 and 722 feet respectively. Some of these locks have been completed, as, for example, at Suresnes, Bougival, Carrières, and Meulan, and the remainder are either in process of construction or are projected. In some cases three locks will in future supply the requirements of navigation, as, for instance, at Bougival, Garenne, Poses, and St. Aubin (Plate 2, Figs. 4 and 6); but Meulan and Port Villez will be served by the old lock and the new large lock only, as no provision has been made for a small lock; at Suresnes, the small lock has been added in prolongation of the old lock (Plate 2, Fig. 5); whilst at Méricourt there will only be the large and small locks of the new type, as no lock has existed there before.

## Cost of Inland Navigation-Works.

In considering the cost of the works for improving the navigable capabilities of the Seine, it must be borne in mind that the works on the Upper, and still more on the Lower Seine, as they exist at present, are the results of successive experimental trials and alterations, so that the total expenditure has been much greater than would be required for the actual erection of the existing works.

*Cost of Upper Seine Works.*—The twelve weirs and locks between Montereau and Paris cost originally £432,500, or about £36,000, on the average, for each weir and lock. These works, completed in 1873, increased the navigable depth from less than 2 feet in dry weather up to 5¼ feet. The lock at Port-à-l'Anglais was deepened in 1869, and a new navigable pass formed in 1870, at a cost of £23,880, which is included in the amount given above. The lock cost about £16,000, out of the total of £36,000; the navigable pass, retaining a depth of water of 10 feet on its sill, cost £37 10*s*.

per lineal foot; and the regulating weir, with its sill 3½ feet higher, cost £21 15*s.* per lineal foot, including £4 12*s.* for the foot-bridge on movable frames added in 1869. The deep pass at Port-à-l'Anglais, with a depth of 13 feet on its sill, and a foot-bridge, cost £62 6*s.* per lineal foot.

The works for raising the navigable depth of the Upper Seine from 5½ to 6½ feet have involved an additional expenditure of £240,000 between 1878 and the end of 1884. These works are now completed; and Mr. Boulé considers that a further sum of £47,500 would amply suffice for these weirs for some years to come, which would raise the total expenditure on the twelve weirs and locks to £720,000, or an average of £60,000 for each weir and lock. Mr. Lavollée estimates the annual cost of maintenance at £3,480 on the average.

*Cost of Lower Seine Works.*—Some of the weirs and locks comprised in the improvement-works authorized in 1878 are as yet unfinished, so that the total cost of the works cannot be ascertained. A sum of £412,000 was allotted in 1846 for the execution of the works for ensuring a navigable depth of 5½ feet. In 1866 a further expenditure of £260,000 was decreed. Mr. Krantz stated, in his Report to the National Assembly in 1872, that the total expenditure on the Lower Seine since the beginning of the century had amounted to £1,058,000; but of this, only £657,300 had been expended on weirs and locks, the remainder having been devoted to dredging, protection of banks, towing-paths, embankments, and accommodation for vessels. The estimated cost of the new works for securing a depth of 10½ feet, authorized in 1878, was £1,280,000; and a further expenditure of £420,000 was allowed in 1880 for the special purpose of extending this increase in depth from the Concorde Bridge right through Paris. This raises the total estimated expenditure on weirs and locks in the Lower Seine to £2,372,000.

Various details of the actual and estimated costs of the new works are given in Mr. de Lagrené's report for 1881,[1] from which it appears that the cost of the lock and weir at Port Villez, including repairs of the frames and alterations in the sills of the passes, amounted to £234,940; the Bougival locks cost £112,800; the Carrières-sous-Poissy locks and cut, £104,600; the Meulan lock and cut cost £95,430; and the estimated cost of the weir and locks at Méricourt was £240,000.

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[1] Navigation de la Seine, 3me Section. Rapport de l'ingénieur en chef pour l'inspection de 1881, pp. 121–138.

## Navigation.

*Upper Seine Navigation.*—The width of the navigable channel of the Upper Seine varies from 115 to 164 feet. The vessels navigating this section of the river convey loads of from 100 to 350 tons of merchandise; they go in trains, for, as the trade is mainly towards Paris, the same tug which conveys the loaded vessels down-stream can tow the vessels when empty up-stream. Traction by horses or men has almost disappeared on the river since the improvements in depth, and the vessels are towed either by a tug hauling on a sunken chain or by an ordinary steam-tug.

The traffic on the 60½ miles of the first section of the Seine, between Montereau and the entrance to the St. Martin Canal, which Mr. Krantz reckoned at about 1,245,000 tons of merchandise in 1868, and which did not exceed 1,500,000 tons before the increase in depth from 5¼ to 6½ feet, reached 2,100,000 tons in 1882, and 2,300,000 tons in 1883, showing the impulse given to the river traffic by the improved facilities for navigation.

*Lower Seine Navigation.*—The tonnage of the vessels regularly navigating the Lower Seine varies from 250 to 500 tons; but when the river is high, vessels of nearly 800 tons pass along, and as soon as the works in progress are completed, the river will be available for vessels of 1,000 tons. Comparatively few vessels are now towed by horses, and only those of the smallest class. Traction is generally conducted on the Lower Seine by one of the following methods: steamers carrying cargo; steamers both carrying cargo and towing; steam-tugs; portable steam-propellers fixed at the stern of the vessel; and tugs hauling on an immersed chain.

The Lower Seine is divided into two sections, namely, the second section of the Seine, from the end of the first section, at the entrance of the St. Martin Canal, down to the mouth of the Oise just above Andrésy weir, a distance of 25¾ miles; and the third section, from the mouth of the Oise to Rouen, having a length of 107 miles (Plate 2, Fig. 1). Owing to the considerable amount of traffic brought into the second section from the Upper Seine and the Oise for Paris, and the imperfect canalization of the third section, the traffic per ton-mile in the third section was only a little in excess of that in the second section in 1868, in spite of the great difference in their lengths, amounting to 53,334,000 ton-miles in the second section, and 58,421,000 ton-miles in the third section. By 1878, however, the traffic in the second section was somewhat reduced, whereas the traffic in the third section had increased,

amounting respectively to 49,504,000 ton-miles and 68,033,000 ton-miles. In 1881, the traffic per ton-mile in the second section again approximated to that of the third section, being 67,656,000 ton-miles as compared with 71,351,000 ton-miles in the third section, owing probably to the development of traffic from the Upper Seine. The traffic, however, of the third section has made a rapid advance since 1881, having attained 84,713,000 ton-miles in 1884.

Hydraulic machinery has been provided at the Bougival locks for working the gates and sluices, and for the haulage of vessels through the locks, because a considerably larger number of vessels pass through these locks than through any of the other locks on the Lower Seine. This is due to the passage through the Bougival locks of all the vessels from the Oise bound for Paris, as well as those coming up the Seine; whilst some of them afterwards diverge into the St. Denis Canal below Suresnes. The traffic through the locks at Suresnes, though notably less than at Bougival, is far ahead of that through the locks below Bougival.

The navigation of the river is free both by day and by night, no tolls being charged, for the lock-keepers are paid by the State, and are bound to pass vessels at any time when required, receiving an extra payment for each lockage effected at night. The locks and weirs are lighted at night with coloured lamps so as to indicate the navigable channel, and some of the bridges are also lighted for navigation; and special regulations exist relative to the lights to be exhibited at night by vessels on the river.

## III. ESTUARY-WORKS.

The improvement-works carried out on the tidal Seine are much simpler in character than the inland-works previously described, for they consist merely of mounds of rubble chalk forming longitudinal training-walls on each side of the channel; but they have produced most important changes in the navigable channel, and in the estuary beyond (Plate 4, Figs. 1 to 7, and Plate 5, Figs. 1 to 4).

The position of Rouen naturally marked it out for an inland port, for whilst situated near the head of the tidal Seine, it possesses water-communication with Paris. Whereas, however, the river has a stable bed in rock, clay, and gravel, with a good natural depth for 39 miles down to La Mailleraye, about half-way between Rouen and the sea; below this point, it flowed in a shallow, winding, changing channel through shifting sand-banks to the sea (Plate 5, Fig. 1). The shoals rose so high at Aizier and Villequier

that the depth of water over them at high-water spring-tides was about 10 feet, so that only vessels of from 100 to 200 tons could go up the river, and they frequently had to wait for a high enough tide. Four days at least were occupied in the voyage between the sea and Rouen; and the perils of navigation were aggravated by the bore, caused by the impediments offered by the shoals to the flood-tide in its passage up the estuary, and consequently wrecks frequently occurred. The charge for freight was 8*s*. per ton, and the rate of insurance was ½ per cent.

From the time of Louis XV. great anxiety was manifested for remedying the perils of the estuary, and numerous schemes were put forward by various engineers for the improvement of the river. Mr. Cachin, engineer of the Cherbourg breakwater, about the year 1770, proposed to avoid the estuary altogether by constructing a ship-canal along the left bank from near Villequier down to Honfleur. Others suggested the improvement of the river by groynes or by weirs; whilst Mr. Frimot proposed to narrow and train the river by two rows of caissons, along each side, filled with stones; and Mr. Bleschamps conceived the idea of substituting simple rubble longitudinal training-walls. Nothing, however, was accomplished till, in 1845, Mr. Bouniceau designed a plan for the improvement of the estuary by rubble training-walls from La Mailleraye to Havre, backed up by forcible arguments for its adoption[1] (Plate 4, Figs. 1 and 9). In the following year, 1846, the improvement of the navigation between Villequier and Quillebeuf, by this method, was authorized: the left bank was commenced at Belcinac Island, opposite Villequier, in 1848, and the training-works reached Quillebeuf in 1851. These works immediately increased the depth at the shoals from 10½ to 21⅓ feet at spring-tides. Accordingly the extension of the training-walls was decreed, in 1852, from Villequier up to La Mailleraye, and from Quillebeuf down to Tancarville and La Roque (Plate 4, Fig. 1). The dredging also of the Meules bank, a little below La Mailleraye, was undertaken at the same time. The upper works were completed in 1856, the extension to Tancarville on the right bank having been finished in 1855; but the extension on the left bank to La Roque, with a cross bank from the point to its extremity in order to protect it, was not terminated till 1859. The channel between the embankments was made 980 feet wide at Villequier, increasing to 1,310 feet at Quillebeuf, and to 1,640 feet at Tancarville. The above works provided a deep, stable channel

[1] "Étude sur la navigation des rivières à marées." M. Bouniceau, p. 152, pl. 2.

down to Tancarville. Below this point, however, the channel diverged from the southern embankment towards the north, and then turned southwards to Berville, and it was also shallow and changeable. Moreover the bore, which had been greatly reduced since 1854, reappeared with all its former power at the close of 1858, and did considerable damage to the retaining-walls. A prolongation of the northern training-wall was accordingly authorized in 1861 from Tancarville to La Roque, and the repair of the banks was commenced. The northern training-wall was completed to La Roque in 1863; and a further extension of the walls to Berville was decreed, which was completed in 1869 (Plate 5, Fig. 2). A prolongation of the southern bank for 1,300 yards below the mouth of the Rille was carried out in 1869–70; but a proposed prolongation of the northern bank in 1871, for a distance of 1¼ mile, was refused on behalf of Havre. The embankments, therefore, remain now at the points they had reached in 1870, except that most of the bank below the Rille has become covered with sand, and considerable repairs are being executed. The actual lengths of the training-walls are given below, for they do not correspond with the embanked channel, since the river flows in some parts close along its natural bank.

| —— | La Mailleraye to Caudebec. | Caudebec to La Vaquerie. | La Vaquerie to Quillebeuf. | Quillebeuf to La Rille. | Below La Rille | Total. |
|---|---|---|---|---|---|---|
| | Yards. | Yards. | Yards. | Yards. | Yards. | Yards. |
| Left bank . . | 6,671 | 10,390 | 1,006 | 15,311 | 1,312 | 34,690 |
| Right bank . . | 6,835 | 9,077 | 13,670 | 15,311 | .. | 44,893 |

The total length of the training-walls is therefore about 45 miles.

The original training-walls consisted simply of rubble chalk quarried from the cliffs bordering the river in places. The mound was formed by tipping in the chalk at random below low-water, and placing the blocks, filling up the interstices, and trimming the slopes above low-water; it was made about 6½ feet wide at the top, with a slope of 1 to 1 on the land side, and slopes varying from 1½ to 1 up to 8 to 1 in exceptionally exposed places on the river side (Plate 4, Fig. 3.) Piling also was placed in some parts along the toe of the river slope. The cost per cubic yard of mound put in place amounted to about 1*s.* 0½*d.* The mounds were raised to high-water level down to Tancarville on the north, and to La Roque on the south, except between La Mailleraye and Caudebec on the south side, where the bank was kept low for the

sake of economy. Below Tancarville and La Roque low banks were adopted by Mr. Emmery, raised only 3¼ feet and 1⅔ foot respectively above low-water of spring-tides, so that they might have less influence in promoting the accumulation of deposits, which had already become a serious consideration.

The bore, which at some points causes a rapid rise in the river of about 10 feet (Plate 4, Figs. 10 and 11), and appears in places as a breaking wave, together with the deepening of the river-bed by the training-works, disturbed and undermined the training-walls, so that they required raising (Plate 4, Fig. 4). The simple addition of rubble chalk on the top of the old mounds was pursued for several years; but these banks could not efficiently resist the action of the bore. Accordingly, in 1878, a new type of mound was adopted, the river slope being protected by a facing of concrete from 8 to 12 inches thick, and secured where necessary from undermining by a concrete apron, 15 inches thick and 10 feet wide, with piling and planking at its outer edge (Plate 4, Figs. 5 and 6). The training-walls are being gradually reconstructed in this manner, which secures them against the bore. The low south training-wall below La Roque experienced such injuries from the rush of the tide over it at certain periods, that it has been raised to mean high-water level, as shown in Plate 4, Fig. 7; and the north wall below Tancarville must be similarly dealt with.

The total cost of the works up to 1876 amounted to £678,060; in 1878 a sum of £144,000 was allotted for the reconstruction of the banks; and it was proposed in 1883 to expend a further sum of £376,000 in completing these repairs.

The training-works have effected a very remarkable increase in the depth between La Mailleraye and Berville, as indicated by comparing the longitudinal sections of the channel in 1824 and 1875 (Plate 4, Fig. 2). The minimum navigation-depth between Havre and Rouen, at high-water neap-tides, has been increased from 10 feet up to 18 feet. Vessels of 2,000 tons can navigate the river; and it has been found possible, under favourable conditions, to bring up a vessel drawing 21 feet. Moreover, the charge for freight between Havre and Rouen has been reduced to one-half; and the rate of insurance for Rouen is the same as for Havre. The trade of Rouen has consequently greatly increased, and it has become the fifth port of France. The Meules bank is the shallowest point below La Mailleraye, but it could be still further lowered by dredging.

Considerable alterations have been effected in the river-channel at Rouen, but mainly with the object of increasing the quay

accommodation of the port. These works consist in regulating the river where it is intersected by islands, so as to form one enlarged main channel, by modifying the lines of the banks, and joining the islands to the mainland. By this means, the wasted area of the islands is available for quay space; and the regulated banks are lined with quay walls.[1] The shallow parts of the river between Rouen and St. Aubin are to be dredged, so as to provide a minimum depth of 13½ feet at high-water neap-tides for the up-river navigation.

The range of spring-tides, which amounts to 23 feet 7 inches at the mouth of the Seine, is reduced to about 10 feet at La Mailleraye, and to 6 feet 7 inches at Rouen. The variations in the tidal rise and flow at different places on the river are clearly indicated by the tidal diagrams (Plate 4, Figs. 10, 11, and 12). The improvement effected in the channel by the training-works has caused a lowering of the low-water at Rouen by 2 feet 3½ inches at spring-tides, and 2 feet 9½ inches at neaps; whilst the high-water level has remained unaltered. The tide reaches Rouen fifty-eight minutes earlier than formerly, namely about two and a quarter hours after high-water at Havre; whilst high-water at Rouen occurs from five and a quarter to six and a quarter hours later than at Havre.

The training-walls have more than fulfilled the expectations of their effects on the depth of the channel between them; but their deepening influence extends very little beyond their extremities. Nevertheless, by bringing the deep channel of the river much nearer the sea, the intervening gap of shallow channel in the estuary is readily traversed at high-water in fine weather. Moreover, owing to the greater range of tide in the lower estuary, the depth near high-water in the navigable channel through the estuary approximates to that within the trained channel, so that little inconvenience would be felt from the absence of an improved depth between Berville and the sea if the estuary channel was stable (Plate 4, Fig. 2). This channel, however, is constantly shifting, and though it is carefully marked by buoys, the changes cannot be immediately indicated during stormy weather, when the greatest alterations occur, and when a knowledge of the exact position of the channel is most urgently needed (Appendix I.). Also in fogs, an altered channel, even though marked by buoys,

[1] A description and plan of these works will be found in "Harbours and Docks," L. F. Vernon-Harcourt, pp. 428 and 619, and Plate 13, Fig. 2, and Plate 15, Fig. 15.

is not readily discovered. Accordingly vessels incur considerable risk at times, and are occasionally wrecked in traversing the interval between the sea and Berville. The growing trade of Rouen, and the improvements in progress above, enhance the importance of a safe and easy channel between Rouen and the sea. The shiftings of the estuary channel can only be prevented by an extension of the training-walls, which would also increase the depth.

The training-walls have been executed very nearly in accordance with the lines indicated by Mr. Bouniceau in 1845, but they have not been carried out to the extent he proposed. The Author pointed out in his Paper on "Harbours and Estuaries"[1] that Mr. Bouniceau had considered accretion in the estuary as an extremely remote consequence of the training-works; whereas by the time the training-walls reached Tancarville and La Roque, the accretions had been so rapid and considerable that the walls were kept low beyond these points, and the works were finally stopped in 1870 for fear of endangering the approaches to Havre, the second port of France, by the silting-up of the estuary. A survey made by Mr. Estignard in 1875, showed that a loss of 272,000,000 cubic yards of capacity at high-water had occurred in the estuary, in spite of the increased volume within the limits of the trained channel, since the commencement of the works, an amount equivalent to nearly one-third of the total capacity of the estuary. Such a result excited so much anxiety about the maintenance of the estuary that another survey was made by Mr. Germain in 1880, from which it appeared that the capacity of the estuary had further decreased by 40,000,000 cubic yards in the five years from 1875 to 1880 (Appendix III.), making a total reduction of 312,000,000 cubic yards in the capacity of the estuary since the commencement of the works.[2] This enormous accretion has enabled large tracts of land to be reclaimed, and altogether about 25,000 acres have been raised above high-water mark; some portions are only partially covered by very high tides, and the areas lying above Tancarville and La Roque have been completely reclaimed (Plate 4, Fig. 1). The value of these lands when fully reclaimed is estimated at about £1,600,000, thus amounting to more than the expenditure on the works; but the Government have admitted the right of the riparian landowners to a share in these reclamations. The lands thus raised

[1] Minutes of Proceedings Inst. C.E. vol. lxx. p. 21.

[2] The accretion measured in the outer estuary, between 1875 and 1880, mainly occurred in deep water, which does not affect the tidal capacity; but it equally diminished the capacity of the estuary, and caused a very important alteration by greatly reducing the depth in the main outlet channel.

extend as far as Honfleur on the southern shore, and 8½ miles beyond the ends of the training-walls on the north, which shows that the accreting influence of these walls extends far beyond their extremities.

The prolongation of the training-walls has naturally formed the subject of various designs; for whereas Rouen needs a stable and deeper entrance channel, it is essential that the training-works should both supply a channel for Honfleur on the south, and at the same time not divert the ebb and flow of the tide from the entrance to Havre on the north, either by deviating the deep-water channel towards the south, or by greatly restricting the estuary. The principal schemes are shown in Plate 4, Fig. 9; and the most important and latest of these is that of Mr. Lavoinne, propounded in his book on "La Seine Maritime" published in 1885 after his lamented decease. Having charge as Engineer-in-Chief of the tidal Seine from Rouen to the sea, and residing at Rouen, he necessarily was much interested in the development of that port by the formation of a satisfactory channel from Berville to the sea, a problem presenting peculiar difficulties and of the highest interest to engineers. It would be impossible to rest content with the present state of the outlet, where a narrow trained channel emerges abruptly into a wide shallow sandy estuary, resulting in a barred shifting channel beyond the ends of the banks, which is likely still further to deteriorate from accretion in the estuary. The difficulties consist in designing a line for the training-walls which shall serve both Honfleur and Havre, and in placing them close enough together to fix and deepen the channel without unduly reducing the tidal capacity of the estuary. Mr. Bouniceau planned a narrow winding channel passing close along Honfleur, and then directed out to sea with the northern bank turning up to Havre (Plate 4, Fig. 9), or an alternative scheme taking the trained channel across the estuary from Honfleur to Havre. Both schemes would have greatly restricted the estuary; and whilst the first scheme diverted the channel away from Havre, the second necessitated a sharp bend and a badly placed outlet.

Mr. Lemire proposed a narrow channel, like Mr. Bouniceau's, down to Honfleur, but more sinuous, though it expanded beyond to a trumpet-shaped mouth, an improvement in this respect on Mr. Bouniceau's scheme (Plate 4, Fig. 9).

Mr. Vauthier, in his report to the municipality of Rouen in 1881, indicated the plan he advised for dealing with the estuary. It consists of two training-walls diverging to Havre on the north, and to Honfleur on the south, in continuation of the present channel

which he proposed to widen out up to Quillebeuf, so that the widening out towards the sea might be more gradual (Plate 4, Fig. 9). A detached portion of wall near the Ratier Bank would prolong the southern training-wall to the sea, resembling in this feature Mr. Lemire's design. It has, however, been objected to Mr. Vauthier's scheme that his training-walls, being so far apart, and mainly on banks already considerably raised by accretion, would have little influence on the channel between them.

Mr. Lavoinne adopts a middle course between the previous schemes, for whilst interfering less with the estuary than Mr. Bouniceau or Mr. Lemire, he places his walls much closer together than Mr. Vauthier, though proposing the same modifications of the existing walls between Quillebeuf and Berville (Plate 4, Fig. 9). Before entering upon the consideration of his scheme, Mr. Lavoinne discusses in his book the results of the hydrographical surveys of Mr. Estignard and Mr. Germain, and the modifications in the tides at Havre observed by Mr. Quinette de Rochemont, M. Inst. C.E., and attributed by that engineer to the silting-up of the estuary. The time of high-water at Havre has advanced thirty-eight minutes; and the reverse current, which makes its appearance near Havre some time before high water, has also advanced about thirty minutes. Mr. Lavoinne considers that this change is due to the increase in depth seawards of Havre, and not to the influence of the diminished capacity of the estuary. Whilst, however, it is possible that the increase in depth has somewhat facilitated the approach of the tide to Havre, it is difficult to admit that an advance of the lines of soundings of which the maximum is 400 yards should have effected such a notable advance in the period of the tide, and that the great diminution in the capacity of the estuary has had no influence on the result. It is far more probable that both causes have contributed to the change, but in what proportions it would be very difficult to determine, though the Author thinks that the preponderating influence must be due to the very great alteration in the estuary produced by the training-walls. As, however, Mr. Lavoinne attributes the deepening in front of Havre to the training-works, the question is one rather of scientific interest than of importance with regard to the future of the estuary, for, according both to Mr. Lavoinne's and Mr. de Rochemont's views, an extension of the training-walls would occasion further modifications in the tidal regime.

Mr. Lavoinne's remarks on the variations in depth, deduced from the hydrographical surveys, are of much greater importance in the consideration of the improvement of the estuary-channel. He

points out that great changes have occurred at the mouth of the estuary in the past as well as recently, and that thirty-two years ago the capacity of the estuary, between the meridians of Honfleur and Cap de la Hève, was actually less than at present, though Mr. Germain's survey indicated a considerable accumulation in the deep-water channels between 1875 and 1880 (Appendix II.). He attributes these changes to the variable action of storms, rather than to the regular ebb and flow of the tide. The Author agrees with these views as regards the outer portion of the estuary, for the increase in depth has occurred at depths where waves would exert far more influence than the tidal flow, and the changes have been so very irregular (Plate 5, Figs. 1 to 4). Moreover, although Mr. Germain discovered that the deep passes had shoaled between 1875 and 1880 (Plate 5, Figs. 3 and 4), he found that there was some increase in capacity in the section above, which would be more subject to the influence of the decrease in tidal-capacity (Appendix III.). Mr. Lavoinne, however, appears to go a step further, and to argue that the great silting-up in the estuary is the result of a period of storms, tending to remove the sands from outside, and to deposit them within the estuary. Accordingly, Mr. Lavoinne is at issue with Mr. Estignard as to the cause of the deposits in the estuary; for the former attributes them mainly to a succession of peculiar meteorological conditions favouring deposit, which might be succeeded by a series of reverse phenomena as previously, though admitting that the training-walls have somewhat aided the deposits by their shelter; whilst the latter considers the accretion to be wholly due to the training-walls. The Author thinks that the construction of the training-walls may have coincided with a series of peculiarly unfavourable meteorological conditions, which has hastened the accretion in the estuary; but the training-walls, by totally altering the condition of the estuary, have undoubtedly permanently fixed the deposits both behind them and in the sheltered bays in front, so that a recurrence of favourable conditions would no longer, as of old, clear out the estuary. The wanderings of the channels have been restricted, from the ends of the training-walls to a line between Honfleur and La Hoc, by the land which has been raised beyond the influence of the tides, so that the reductions in the estuary are permanent (Plate 5, Figs. 1 and 2; and Plate 4, Figs. 1 and 8).

It is, moreover, probable that the considerable increase in capacity of the outer estuary, which occurred between 1853 and 1875 (see Tables in Appendix II.), may have been due to the sand

and silt, brought up by the waves and flood-tide, having been deposited behind the training-walls, and having thus been prevented from being carried out again by the ebb-tide, and redeposited in the lower estuary; for this period of erosion in the outer estuary approximately coincides with the period during which the training-walls exercised their greatest influence in promoting the enormous accretions measured by Mr. Estignard. Mr. Lavoinne has overlooked this possibility, and has considered the changes as due entirely to meteorological oscillations, and quite uninfluenced by the convulsion which has occurred in the upper estuary in consequence of the training-works.

Mr. Lavoinne's scheme serves Honfleur by placing the southern concave training-wall close alongside it. The mouth of the estuary is also narrowed by prolonging the southern wall across the existing southern channel, and all along the Ratier Bank (Plate 4, Fig. 9). Besides narrowing the limits of the tidal flow, Mr. Lavoinne anticipates a benefit to the estuary by cutting off the southern channel, up which the tide brings a good deal of silt, whereas the middle and northern channels are tolerably clear; and considers that, by keeping the walls low, the accumulation of deposit behind them will be prevented or delayed. The experience, however, derived from the low banks beyond Tancarville and La Roque affords little hope of such a result.

The Author, whilst acknowledging the great ability displayed by Mr. Lavoinne in his discussion of the subject, and in the scheme he has advised, and whilst agreeing with some of the points urged in favour of the scheme, nevertheless considers that there are important objections to some parts of the proposal. He has already, in his Paper on "Harbours and Estuaries,"[1] expressed full concurrence with the proposed widening out of the existing training-walls, first propounded by Mr. Vauthier; and he adheres to the view that it would be very advantageous if such widening could be extended still higher up, so that the tide might be more freely admitted, and that the widening out towards the mouth of the estuary might be more gradual. He considers, however, that the continuously concave southern training-wall, whilst very favourable to Honfleur, will unduly keep the ebb-current to that side, and therefore away from Havre. Also he thinks that the extension of the wall along the Ratier Bank will act like a groyne, and, arresting the silt-bearing southern current, will connect Trouville Bank with the shore, and lead to a large accumulation

[1] Minutes of Proceedings Inst. C.E. vol. lxx.

of deposit in front of Trouville. Moreover, he is of opinion that the exposed position of the wall on shifting sand-banks will render its maintenance very difficult till deposit has accumulated behind it, and also that the low walls proposed will not prevent accretion.

The channel just below the training-walls is influenced by the ebbing current issuing from the trained channel till it gradually loses its effect; the outer channels are formed by the flood-tide, and modified by the action of storms. Between these channels, there is a zone in the estuary where the flood and the ebb have varying influences, resulting in a continually shifting channel (Plate 5, Fig. 2; and Plate 4, Figs. 1 and 8). In order to improve this central portion of channel, it is necessary to make the ebb act more directly upon it, and as far as possible to concentrate the flood in the same direction. This necessitates the restriction of this portion of the estuary by training-walls, and the Author has given in Plate 4, Fig. 8, the direction for the walls which he believes would accomplish the desired result. He has retained the enlargement in width of the existing trained channel, as advocated by Mr. Vauthier and Mr. Lavoinne, but with the proviso that he would much wish to extend it further up if it was possible. He has dispensed with the continuous curve by narrowing the width slightly more than Mr. Lavoinne at the change of curvature, and by forming a short channel of access to Honfleur, which could be very easily maintained by dredging. This will enable the channel to be carried more directly towards the position of the central deep, and more over towards Havre. He has only placed a regulating wall beyond Honfleur, as he considers that the flood should be freely admitted by all three channels, and concentrated by the funnel-shaped mouth towards Honfleur, where the ebb would be losing its influence. The southern training-wall would not be prejudicial to Trouville; and the northern training-wall would be sheltered from north-westerly storms, and would be soon protected by accretion at the back. The tidal capacity of the estuary will undoubtedly be still further reduced; but by prolonging the influence of the ebb, which is powerfully reinforced by the large discharge of clear fresh water from the Seine, and by bringing the trained channel down to the place where deep water is maintained by the flood-tide and the action of waves, it may reasonably be anticipated that a stable and adequately deep channel will be secured, which will provide a proper access to Rouen without injury either to Havre or to Honfleur.

The Tancarville Canal is in course of construction for the purpose of enabling small vessels to pass between Havre and the

trained channel without encountering the dangers of the exposed estuary (Plate 4, Fig. 1). Formerly a channel existed along the northern shore, under the shelter of Hoc Point, by which small vessels could reach the estuary above; but the site of this channel has been converted into land by the accretions. The canal extends from the docks at Havre to the trained channel at Tancarville; and the locks and other works of construction on it are being made large enough to admit of the passage of sea-going vessels from Havre to the river at Tancarville, by merely excavating an enlarged section for the canal in the event of such a deterioration of the estuary as to bar the river channel. The Author, however, thinks that the necessity for a ship-canal between Havre and Tancarville may be obviated by judiciously-designed training-works, aided by the large freshwater discharge of the Seine, and the deep water outside.

## Concluding Remarks.

The Author, in conclusion, must acknowledge his obligations to Mr. Schwebelé, the Librarian of the École des Ponts et Chausées at Paris, for aiding his inquiries; to Mr. Boulé for information about Suresnes weir, and the cost of the Upper Seine works; to Mr. Lavollée for a section of the Upper Seine and other particulars; and to Mr. Caméré for several drawings and details of the new weirs on the Lower Seine.

The Author hopes that the details he has given about the hydrology of the Seine basin may lead to an extension of hydrological investigations in the river-basins of England and her colonies, and to the adoption of the system of giving warnings of floods.

Though there may be no scope in Great Britain for works equal in magnitude to the new weirs on the Lower Seine, he trusts that the descriptions of these novel types of weirs, whilst necessarily of general engineering interest as marking a progress in this branch of science, may be of special value to engineers engaged in river-works in the Colonies, in India, and in America.

The experience to be gathered from the training-works in the Seine estuary is, in his opinion, of the highest importance, for he believes that, had the results of terminating training-walls in the middle of a sandy estuary been fully appreciated, the cost of two abortive attempts to obtain authority to carry out similar works in the estuary of the Mersey, far less favoured by nature

than the Seine, might have been saved. For the Seine works demonstrate that accretion is the result of training-walls, whether high or low, in a shifting sandy estuary, and that a deep channel can only be secured by prolonging the training-walls to deep water. The Ribble is an estuary similar in many respects to the Seine, but far less favourably situated as regards freshwater flow and depth at its mouth. Its history also shows that accretion occurs with low training-walls, and that training-works cannot stop in the middle of a wide sandy estuary. The modifications needed in the width between the training-walls of the Seine will serve as a useful warning to prevent the tidal flow of the Ribble from being similarly curtailed.

The communication is illustrated by a series of tracings, to a small scale, from which Plates 1, 2, 3 and 4 have been engraved.

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# APPENDICES.

## APPENDIX I.

### Changes of the Navigable Channel in the Seine Estuary.

Mr. Vauthier, in his Report on the Estuary of the Seine, gives a plan showing some of the changes in the navigable channel between 1874 and 1880: Mr. Lavoinne, in his "Seine Maritime" (p. 160) furnishes a plan indicating changes between 1879 and 1882; and Mr. Audra, in a plan in "Le Génie Civil" (October 1885, p. 411), brings the series down from 1879 to June 1885. The lines representing the channels at the various dates appear compressed into a compact bundle for a little distance from the ends of the training-walls, and after divergencies below, extending right across the estuary, they reassemble again between the Amfard and Ratier banks, a little to the east of the meridian of Havre. The greatest divergence in the earlier series occurs eastwards of Honfleur, about half-way between Hoc Point and the ends of the training-walls; whereas, in the later series, the divergence is more marked to the west of Honfleur, due south of Hoc Point. The transition of the channel across the estuary is sometimes very rapid, the extremes of the series 1874–1880 having occurred between May and December 1878. These changes materially affect the access to Honfleur; for, whereas in 1878, 1879, and February 1880, the main channel passed close to Honfleur, in March 1880 it had shifted to the centre of the estuary; in 1881 it approached Hoc Point, and in June 1885 it ran close along the point, at the furthest possible distance from Honfleur. In considering these changes, however, it must be remembered that the lines only indicate the best out of two or three channels that may be simultaneously in existence, and therefore that a change in the position of the lines does not necessarily imply a complete transposition of the channel, but may result from the gradual improvement of one channel, and the deterioration of another which is thus superseded.

## APPENDIX II.

### Alterations in the Outer Estuary of the Seine to the West of Honfleur.

The alterations which have taken place in the outer estuary, between the meridians of Honfleur and Cap de la Hève, between 1834 and 1883, as gathered from the hydrographical surveys, are illustrated in a tabular form by Mr. Lavoinne in his book ("La Seine Maritime et son Estuaire," p. 151), which enables modifications in capacity at the different periods to be readily appreciated. The estuary is divided into two portions in both the Tables given; in the first Table, the portions north and south of the Amfard Bank are separately considered;

and in the second Table, the portions east and west of the Amfard meridian are contrasted. The Tables, converted into English measures, are as follows:—

| Periods. | Years. | Alterations in the Banks. | | | | | |
|---|---|---|---|---|---|---|---|
| | | North of Amfard. | | South of Amfard. | | Total. | |
| | | Accretion. | Erosion. | Accretion. | Erosion. | Accretion. | Erosion. |
| | No. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. |
| 1834–1853 | 19 | 14,841,300 | .. | 51,480,200 | .. | 66,321,500 | .. |
| 1853–1863 | 10 | 54,059,100 | .. | .. | 75,305,000 | .. | 21,245,900 |
| 1863–1875 | 12 | .. | 10,141,400 | .. | 37,011,200 | .. | 47,152,600 |
| 1875–1880 | 5 | 5,575,200 | .. | 50,050,900 | .. | 55,626,100 | .. |
| 1880–1883 | 3 | 11,905,000 | .. | .. | 9,986,900 | 1,918,100 | .. |
| Total result 1834–1883 | Accretion | 76,239,200 | | | | 55,467,200 | |
| | Erosion | | | 20,772,000 | | | |

| Periods. | Years. | Alterations in the Banks. | | | | | |
|---|---|---|---|---|---|---|---|
| | | West of Amfard. | | East of Amfard. | | Total. | |
| | | Accretion. | Erosion. | Accretion. | Erosion. | Accretion. | Erosion. |
| | No. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. |
| 1834–1853 | 19 | 59,932,100 | .. | 6,389,400 | .. | 66,321,500 | .. |
| 1853–1863 | 10 | .. | 22,448,400 | 1,202,500 | .. | .. | 21,245,900 |
| 1863–1875 | 12 | .. | 89,958,500 | .. | 7,194,100 | .. | 47,152,600 |
| 1875–1880 | 5 | 33,238,400 | .. | 22,387,700 | .. | 55,626,100 | .. |
| 1880–1883 | 3 | 516,800 | .. | 1,401,300 | .. | 1,918,100 | .. |
| Total result 1834–1883 | Accretion | 31,280,400 | | 24,186,800 | | 55,467,200 | |

Mr. Vauthier has drawn out a somewhat more elaborate Table in "Le Génie Civil" (September 19, 1885, p. 331), showing the changes in the outer estuary during the same period of forty-nine years, including in addition the results of surveys taken in 1866 and 1869. His Table refers to the portion of the estuary west of Honfleur, excluding the part to the north-east of Hoc Point, and extending 6,400 feet west of Cap de la Hève. This area is separated into eight divisions; and the capacity of the estuary below the zero of the marine charts (lowest low-water), less the volume of any banks rising above that level, is given for each division at the dates of the several surveys, together with the yearly volume of accretion or erosion in each division in the intervals between the successive surveys. A summary of the total results furnished by the Table for the whole area under consideration is given below:—

| 1834. | 1853. | 1863. | 1866. | 1869. | 1875. | 1880. |
|---|---|---|---|---|---|---|
| Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. | Cubic yards. |
| 433,348,000 | 387,423,000 | 414,604,000 | 437,756,000 | 490,168,000 | 486,768,000 | 441,628,000 |
| Accretion | 45,925,000 | | | | 8,400,000 | 45,140,000 |
| Erosion | | 27,181,000 | 23,152,000 | 52,412,000 | | |

The first line in the above Table gives the capacity of the estuary below the zero at the date of each survey; and the second and third lines give the total amount of accretion or erosion, respectively, which has occurred in the interval, as indicated by the change in capacity.

Both Mr. Lavoinne and Mr. Vauthier agree in deducing from their Tables that the outer estuary is in a state of continual change; that the alterations in capacity by successive accretions and erosions result from variations in the influence of the natural phenomena producing them, and that these changes have no apparent connection with the great alterations which have taken place in the upper estuary.

The large modifications which may occur in the rate of change within a short interval are distinctly indicated by comparing the results of the surveys of 1880 and 1883 in the last two periods of Mr. Lavoinne's Tables, and show the very unstable nature of the outer estuary. Nevertheless it is very remarkable that the only periods during which erosion has been observed hitherto, in the lower estuary, coincide with the construction of the training-walls in the upper estuary; whereas before their commencement, and since their completion, accretion has greatly predominated, and has been more rapid in the latter period than in the former.

## APPENDIX III.

### Changes in the Seine Estuary between 1875 and 1880.

The following extract from Mr. Germain's report of 1881 shows the changes which took place in the estuary between Mr. Estignard's survey of 1875 and Mr. Germain's survey of 1880; the area of the estuary below the training-walls being divided into a series of bands, running north and south, each 1,000 toises (6,395 feet) in width.

"To sum up, starting from the meridian of the Rille lights, and proceeding westwards, we find, in the Bay of the Seine, between that meridian and one 9,000 toises east of the Hève lighthouse—[1]

| Toises. | 1875–1880. Cubic Yards. |
|---|---|
| Rille lights to 9,000 E. (Fiquefleur) . . . . . | 1,951,300 accretion. |
| „ „ 8,000 E. (Vallée d'Oirdelle) . . . | 8,322,700 erosion. |
| „ „ 7,000 E. (Gainville) . . . . . | 10,215,400 erosion. |
| „ „ 6,000 E. (Honfleur) . . . . . | 11,014,500 erosion. |
| „ „ 5,000 E. (Harfleur) . . . . . | 10,349,100 erosion. |
| „ „ 4,000 E. (Penne de Pic) . . . . | 3,438,500 erosion. |
| „ „ 3,000 E. (Fort des Neiges) . . . . | 7,234,500 accretion. |
| „ „ 2,000 E. (Eure Dock) . . . . . | 22,224,000 accretion. |
| „ „ 1;000 E. (St. Vincent du Havre) . . | 40,192,200 accretion. |
| „ „ 0 (Hève Lighthouse) . . . | 44,611,600 accretion. |
| „ „ 1,000 W. (St. Christophe) . . . . | 40,244,100 accretion. |

Accordingly the volume of accretion, between 1875 and 1880, amounts to over 40 million cubic yards, deposited between the meridian of the extremity of the

[1] This first division has a width of about 2,200 toises.

Seine training-walls, and a meridian about 1¼ mile west of La Hève (3 miles west of the entrance to the port of Havre) which appears to be the limit seawards of the modifications in depth of the Bay of the Seine."

"Moreover it should be noted that almost the whole of these accretions (over 32 million cubic yards) have been deposited between the meridians of La Hève and Fort des Neiges, in the channel between the Amfard and Ratier banks, which has diminished in depth from 59 to 36 feet without any increase in depth occurring in the lateral channels."

Taking the divisions separately, instead of their sum, it appears from the above Table that accretion occurred in the wide division next the training-walls; then erosion in the next three divisions, followed by accretion in all the other divisions except the last.

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## Discussion.

Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL, President, observed that the Author had already enriched the Minutes of Proceedings of the Institution by Papers, to which reference had been made during the reading of the present one, and there were probably but few communications that could occupy the members with more advantage than one giving a thorough view of so important a river as the Seine. The Paper had dealt with the system of weirs adopted upon that river, and with the method of giving notice of floods, and of thereby being in a position to be prepared for them, thus preventing their disastrous effects. Lastly, it dealt with works carried out in the lower part of the Seine; works that had been begun within the memory of many of the members then present, and the results of the execution of which had falsified the predictions of the original authors, acting as warnings or instructions to those who had to deal with similar cases in other rivers. As the Author had stated, there were no rivers in England of the magnitude of the Seine, but there were rivers of extreme value, having regard to the commerce upon them and to the interests they served. He trusted the members would discuss the Paper with that thoroughness which was its due.

Mr. Vernon-Harcourt.

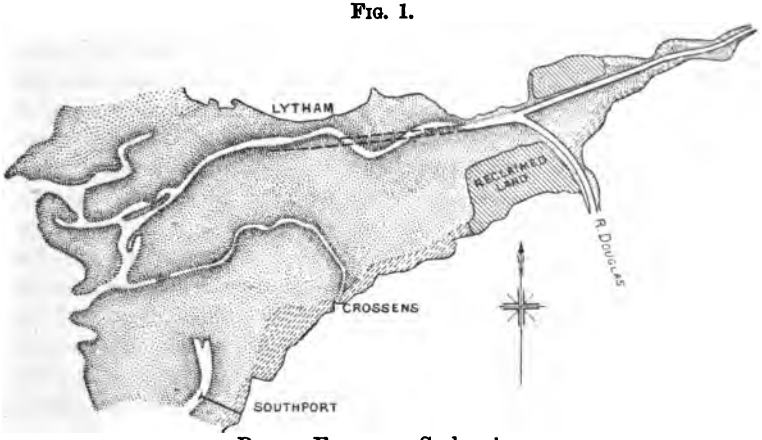
Mr. L. F. VERNON-HARCOURT said that Mr. Caméré, one of the French engineers on the Seine, was sending him some photographs of the weirs. He thought that every one who had to do with rivers in England and France must have been struck with the great importance given in France to the system of inland navigation, and with its great neglect in England. There were, no doubt, some cases in which estuaries had been improved; but he was referring especially to the improvement of the inland portion of rivers, and to canals. In France, every year something was done to improve the depth and capabilities of canals and rivers, and most of the works described in the Paper had been executed within the last twenty-five years, so that the advance of railways in France had not at all stopped inland-navigation works, as it had to a great extent in England. The chief advantage that France had was that the inland-navigation works were under the control of the Government, and that their expenses were paid out of the taxes. Whether such a system could be introduced in England he could not say; but he thought it would be impossible thoroughly to improve the system of inland communication with-

Mr. Vernon-Harcourt.

out some general comprehensive administration of the canals, and of the rivers connected with them. Englishmen might not desire to have a paternal Government like that in France; but he wished to remind the members that there was another democratic country, the United States of America, in which the same system prevailed, the improvements in the rivers, and some of the canals, being executed at the expense of the nation. At the present time, if the Government desired to utilize the services of the unemployed, he thought they could not do better than set them to work upon the construction of inland-navigation works. With reference to training-works, he thought that in early days even Mr. Bouniceau was not aware of what such works would produce. In one of his schemes, Mr. Bouniceau had proposed to form a narrow-trained channel up to Havre. He felt sure that Mr. Bouniceau had not anticipated that he was training the high-water channel of the river, but thought that he was training a low-water channel. If it was possible for engineers by training-works to fix and improve the low-water channel of the river, and at the same time to admit the full volume of tidal water up the river as before, then training-walls would be most excellent things, and very much better even than they now were; but unfortunately, when a river was regulated by training-walls, especially when the tidal flow brought up silt and sand, then in dealing with training-walls, not merely the low-water channel, but the high-water channel also had to be considered. He might mention the case of the Ribble Estuary, which in many respects was similar to the Seine. Fig. 1 showed the training-walls that had been carried out in the Ribble. As in the case of the Seine, they had produced accretion. There, as in the Seine, the estuary was funnel-shaped, and it had been found that the training-walls were not carried far enough, and it had been necessary to get authority to extend them farther, as shown by dotted lines on the plan. Unfortunately, unlike the Seine, the Ribble had a very small basin, about 800 square miles in area instead of 30,000, so that much less fresh water was discharged. Moreover, the training-walls, as authorized, would not be prolonged far enough to reach deep water; and it would be necessary at some future time to apply for a prolongation, as in the case of the Seine. In the proposals for improving the Seine outlet, the training-walls were widened out considerably; whereas it would be noticed that in the Ribble the training-walls were taken to one side, and that very little widening-out was proposed. The result, he believed, would be like that which he feared would occur in the case of Mr.

Lavoinne's scheme as regarded Trouville, but in a greater degree, that the neighbouring seaside place of Southport would have in time sandbanks instead of sea in front of it. If, therefore, training-walls were once begun, it was absolutely necessary to look forward to carrying them into deep water, and to consider that the accre- Mr. Vernon-Harcourt.

FIG. 1.




RIBBLE ESTUARY. Scale $\frac{1}{50000}$.

tions would not only be formed behind, but also along the sides of the Estuary in front of the training-walls. It was, accordingly, most desirable that great pains should be taken, when training-works were begun, to consider to what extent, and in what directions they might have to be eventually carried out.

Mr. BALDWIN LATHAM observed that the Author had taken immense pains to compress a great amount of reliable information into a very small compass, and his labours would be very useful to those who had to study the question of rivers. There were, however, one or two points on which he should have been glad if the Author had given a little more information. It would have been convenient if he had divided the impermeable areas into the different classes of strata which contributed their water-supply. He had given some valuable information as to the relative quantities of water flowing off from diversified strata, such as granite and lias, but he should be glad to know what the Author really meant by impermeable strata, because there was a great difference as to the quantity of water likely to be carried off from equal areas of different impermeable strata. It was, no doubt, common to classify together all clay soils and all rocks of an impermeable character, but there was an immense difference in the character of Mr. Baldwin Latham.

Mr. Baldwin Latham.

the two classes. It might be said that granite, slate, gneiss, and rocks of that character, were absolutely impermeable, as they allowed no water to pass into them; but lias and clays of various descriptions were impermeable, from the fact that they allowed the largest percentage of water to be absorbed by them; so that two qualities diametrically opposite produced impermeable strata. It had been ascertained, by constant gaugings, that the quantity of water absorbed by clay areas was enormous, and that the volume of water flowing from them was very small as compared both with that from areas of a permeable character and also from impermeable areas, where the impermeability was due to the character of the rocks, which would not permit of any water being absorbed. He had ascertained by gaugings during the last ten years, that most of the permeable soils yielded much larger volumes of water to rivers than those that were classed as impermeable strata. He did not allude to clay soils, which when fully saturated caused the water to flow from the surface. It was mentioned in the Paper that a very large area of sand in the basin of the Seine did not contribute any water whatever to the river; but farther on the Author stated that it did probably furnish water to springs in the lower part of the river. It had been ascertained from observations made by the late Mr. Charles Greaves, M. Inst. C.E., upon the question of percolation,[1] that a much larger quantity of water absolutely passed into and through sand-gauges, than into those of any other description of strata, and he was satisfied that upon a closer investigation it would appear that those areas, instead of yielding little or no water to the river Seine, yielded a very large percentage. In another case, the quantity derived from permeable strata was only given as $\frac{1}{7}$ of the total rainfall. It was interesting to notice that the total results of the gauging of the Seine, agreed closely with those of the gaugings of the Thames. The absolute quantities flowing off, as measured in depth, were almost identical during a long series of years. No doubt in the higher districts of the Seine, the rainfall was heavier than in the higher parts of the Thames, but the average quantity of rain was almost identical upon the whole area of the river, and there was a similar agreement with regard to the quantity flowing away. The diminished fall of rain about Paris, which was not quite in the centre of the basin, might, he thought, be readily accounted for. It would naturally occur in such a position, taking into consideration the meteorological conditions.

[1] Minutes of Proceedings Inst. C.E. vol. xlv. p. 19.

Mr. Baldwin Latham.

It would be observed in the first place that the diminished fall occurred over an area of a permeable character. The air over such an area would be naturally drier than in districts where the soil was of an impermeable character. Then it would be noted that farther down the river, the rainfall in the lower districts increased. This was partly due to the flow of the river being in a north-westerly direction. It should also be borne in mind that rain mostly progressed from the west; and the vapours to the west were more laden and in a better condition to drop moisture than those in the east. The consequence was, that owing to the high lands to the west of Paris, the rain would be dropped there before the clouds reached Paris, while the vapours at a loftier elevation passed on to higher grounds. Rainfall was also increased by diminution of temperature, and as the mouth of the Seine lay a considerable distance north of Paris, this was a condition favourable to an increase of rainfall on what appeared to be the moist part of the drainage area. It had been stated in the Paper that the most ancient floods had been the highest. Having recently had occasion to collect records of floods in England, he had found that the result agreed with that stated by the Author; but he did not know whether it was absolutely due to river improvements and the more rapid carrying away of floods, or whether (as might possibly be the case) there were formerly much greater differences between the extremes of drought and flood, than at the present day. With reference to the remarkable flood in the Seine and in other places in 1880, he might mention that in the year 1879 there had been, as far as rainfall was concerned, winter in the summer. It was the most disastrous year ever known in the agricultural annals of the country; and at the end the springs were very high. In the winter of 1879–80, however, there was the smallest rainfall for the season recorded in the South of England for many years, and if that had occurred with the ordinary condition of the springs there would have been a very severe drought. With so much water stored in the ground during the year any little rainfall would take effect. There was no difficulty whatever in predicting floods, especially in a river like the Seine, seeing that the floods always descended from the highest to the lowest districts; but, in rivers of less length than the Seine, the warning that could be given would of course be shorter. In certain conditions of springs and streams predictions might be made with considerable accuracy for long periods beforehand. During the last ten years he had been able to foretell the appearance of one of those remarkable streams in the

Mr. Baldwin Latham. neighbourhood of Croydon, called bourne-flows, which would be found mentioned by many old English writers as presaging war, pestilence, or famine. He had been enabled regularly to predict the day when the spring would break out, and the volume of the water. He would now venture to predict that about the 17th of March a small bourne would break out in Caterham Valley a few hundred yards below the "Rose and Crown."[1] These bourne-flows were produced by a wave of water which passed through the ground from the highest to the lowest part of the district. In a year like the present the difficulty of forecasting became extremely great, owing to the fact that the springs were already rapidly falling in the upper portion of the district, in fact much more rapidly than they were rising in other portions of it.

Mr. Shelford. Mr. W. SHELFORD remarked that the Seine had been for many years represented as a river which had been improved by large works, which works, however, had resulted in a deterioration of the estuary. It was satisfactory, therefore, to have a Paper setting out the facts of the case very fully. Taking a broad view of the general result, it amounted to this, that the channels of the Seine had increased in depth considerably, and that that increase in depth had been accompanied by a diminution in width and a considerable reduction in tidal-capacity. But that was not an unusual thing. Nature had brought about the same result in the Humber, on the outfall of which he had submitted a Paper many years ago to the Institution.[2] The channels in the Humber were now narrower and deeper than ever, and that narrowing and deepening had been accompanied by a considerable reduction in tidal-capacity. On the Thames the same thing had been brought about by nature and art combined, and on the Clyde art had accomplished a similar result. In fact, it was not, he thought, too much to say that in the case of all tidal-rivers where there was an increased depth in the navigable channel, it was accompanied by a diminution of width, and as a rule by a reduction of the tidal-capacity. It was stated in the Paper that from the ends of the training-walls at Berville down to deep water in the meridian of Havre, a distance of about 13 miles, there had been no alteration in the channel. He gathered that it was not silted up, that it was not scoured, and that it was still a shifting channel, which was of course very incon-

[1] This bourne rose in holes in the bourne ditch on the 19th, and continued to the 26th of March, after which it entirely disappeared.

[2] Minutes of Proceedings Inst. C.E. vol. xxviii. p. 472.

venient, and even somewhat dangerous. In those facts he thought there was nothing to lead to the inference that the works of the Seine had led to its deterioration. It appeared to him that if those works were continued judiciously to the sea, the Seine would be an example of one of the most complete successes of engineering works of that character, notwithstanding a very large reduction in tidal-capacity. That reduction amounted to 312,000,000 cubic yards, equivalent to about one-third of the whole tidal-capacity of the Estuary, or about one-half the tidal-capacity of the Mersey. It would be found, on reference to the Author's Paper on "Harbours and Estuaries,"[1] that Mr. Bouniceau had anticipated that storms, waves, and flood-tides would bring up the sands of the estuary, and deposit them in course of time behind the training-walls, and that had actually happened, but in a much shorter time than had been expected. The Author had exhibited a diagram showing the simultaneous tidal curves of flood- and of ebb-tides on the Seine (Plate 4, Fig. 11). It showed the fall of the surface of the water at various times. If the same channel, with the same depth of water in it, had a certain fall, the velocity in that channel, whether at flood- or ebb-tide, would depend entirely on the fall, and it was consequently manifest that, as the fall was much greater on the flood-tide, especially in the earlier portions, than on the ebb-tide, the velocity was greater on the flood than on the ebb, and if the velocity was greater the scouring power must be greater. There was evidently in that estuary a strong natural tendency on the part of the tidal-action to scour material from the bottom, and to transfer it to the upper reaches of the estuary, from which it could only be brought down by great floods of fresh-water, rather than by the ebb-tide. When he saw that condition of things (which was more marked in the Seine than in most rivers) he was not at all astonished to find that there had been so large an accretion. Mr. Shelford.

The Author had stated in his concluding remarks that, "The experience to be gathered from the training-works in the Seine estuary is, in his opinion, of the highest importance, for he believes that, had the results of terminating training-walls in the middle of a sandy estuary been fully appreciated, the cost of two abortive attempts to obtain authority to carry out similar works in the estuary of the Mersey, far less favoured by nature than the Seine, might have been saved." Like many other engineers, Mr. Shelford was engaged in that inquiry, and therefore

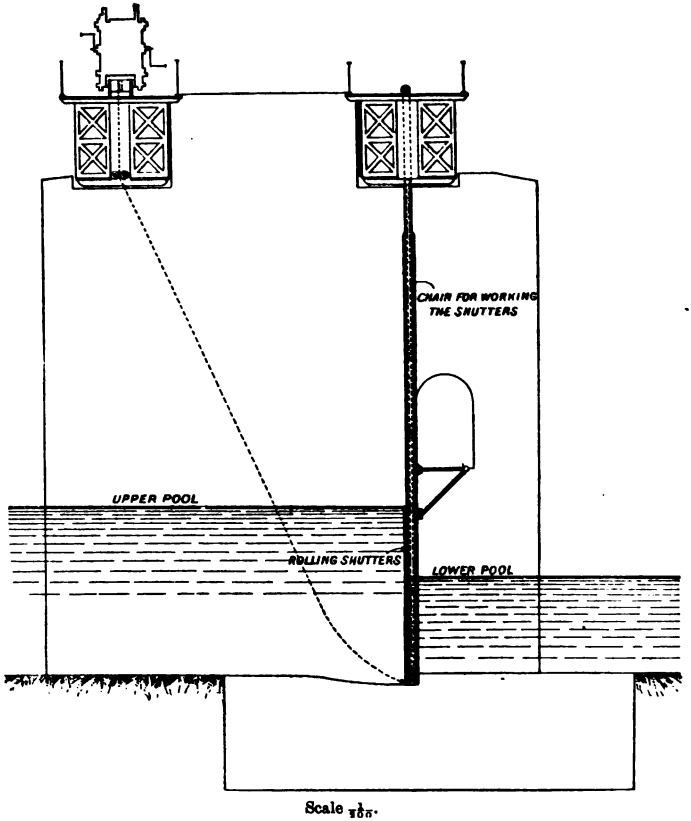
[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 21.

Mr. Shelford. knew something about the circumstances of the case, and he did not think that the statement in the Paper was quite a fair one. The Author had compared the training-walls of the Seine with those proposed in the Mersey, because they terminated in the middle of a sandy estuary. But what were the facts? In the Seine it was true that they did so; they were 10 miles from deep water; in the Mersey it was proposed to terminate the training-walls at a distance much under a mile from Garston Deep. The Mersey, moreover, had a peculiar tidal-action, due to its form. It was not a river, it was a tidal reservoir, in which the flood-tide entered with great force on the Cheshire side, and normally returned on the ebb on the Lancashire side, that side being 50 per cent. shorter than the other; the ebb-tide, therefore, retired by the shortest route, and that action alone would have the effect of making stable the deep-water channel from those training-walls to Garston Deep. It was scarcely fair to compare one river with another. There were great differences between the Mersey and the Seine. One was that there was a great fretting action going on in the Mersey which did not exist in the Seine. Again, there was a bar at the mouth of the Mersey 10 miles out at sea, and there was no similar bar at the mouth of the Seine. That at the mouth of the Mersey was a disgrace to the port of Liverpool. Not only had the Mersey conservators done nothing to remove it, but he did not believe that they even knew the cause of it.

Mr. Vernon-Harcourt. Mr. VERNON-HARCOURT said that several photographs of movable weirs on the Seine were now on the table. They had been sent to him by Mr. Caméré and Mr. Schwebelé. He had also placed on the table two photographs of an English tilting weir at Throstle-nest, near Manchester, across the Irwell, which had been given to him by the designer of the weir, Mr. F. Wiswall, Assoc. M. Inst. C.E. Five photographs were specially referred to by Mr. Caméré as particularly worthy of notice. The first showed Port Villez weir as originally constructed, and the second the same weir as modified in order to enable the frames to be laid down with greater safety. Both the photographs showed well the manner in which the frames were laid down in the bed of the river. The other three represented the frames of Poses weir when lifted. They had been only taken last month, and they showed the amount of *débris* collected in lifting the frames, which Mr. Caméré considered would have rendered it impossible to open properly a weir like that at Port Villez, if such a form of weir had been adopted. Mr. Caméré therefore thought that, in such a situation, the only weir that could be adopted would be one like that erected at Poses. The

members, he was sure, would agree with him in thinking that they were much indebted to Mr. Caméré and to Mr. Schwebelé for so kindly acceding to his request and placing the photographs at their disposal. Fig. 2 represented the system of weir designed by Mr. Tavernier in 1873 for the Saône, to which he had referred in the Paper, p. 27. Mr. Vernon-Harcourt.

FIG. 2.




Scale $\frac{1}{100}$.

SYSTEM OF WEIR DESIGNED FOR THE SAÔNE BY MR. TAVERNIER IN 1873.

Mr. E. LEADER WILLIAMS wished to make some remarks, first on the Upper Seine, and secondly on the Estuary portion of the river. He knew no more interesting river for an engineer to visit than the Seine. He had spent many days upon it with advantage, and if the younger members of the profession wished for a pleasant holiday, they might well take one between Havre and Rouen and Mr. Williams.

Mr. Williams. Paris. There was much to learn on the river; the scenery was charming, and, whether in a row-boat or in a small steamer, such as he had himself hired at Rouen, it was possible to get a good view of the works, and to acquire much useful information. The upper part of the river was an ordinarily canalized river, something like the Severn, and still more like the Weaver, the new works of which he had himself designed. The locks on the Seine were of considerable length, some of them being 520 feet long by 39½ feet wide. He thought that English engineers might learn a lesson from the fact that the French engineers did not put the lock-sills down low enough. The original locks had 5¼ feet of water over the sills, but in a comparatively short space of time they had to be deepened to 6½ feet, and the question was now being debated whether they should not be at a still greater depth. Perhaps he had gone to an extreme on the Weaver in putting the sills down at 15 feet. He had adopted the same width, 40 feet, but the length was only 200 feet, because it was much easier to lengthen a lock than to deepen the sills. French weirs had been well discussed in Mr. Vernon-Harcourt's Paper on that subject. He thought—and he was glad that the Author agreed with him—that they were hardly adapted to English rivers. Solid weirs, like those built by Sir William Cubitt, were, he thought, better adapted to English rivers than any other kind; but if movable dams were required, Mr. F. G. M. Stoney's sluices were admirably fitted for the work. They could be lifted clear of the water to afford sufficient headway for the accommodation of the traffic in times of flood. A lesson had been given by French engineers that was learned on the Severn, namely, that it was no use, after getting out of the tideway to the upper reach of a river where the fall was considerable, say, 12 or 15 inches in a mile, to think of dredging only. It had been tried on the Seine and on the Severn, and had failed. In an ordinary river there was a succession of pools formed by the shoals below, and if these shoals were dredged, the pools were merely lowered, but the navigation was not improved. It was necessary to substitute for the natural shoals something else, and the French engineers on the Seine, like the English engineers on the Aire and Calder and on the Severn, had properly substituted weirs and locks. It was satisfactory to learn that the trade on the Upper Seine had doubled between 1868 and 1884. A navigation could be made to prosper, only by increasing the size of the vessels which plied on it; the expenditure did not grow in the same proportion. There was the advantage of a permanent way that did not wear out; and by

Mr. Williams.

increasing the sectional-area so as to enable vessels of larger burden to pass with facility, the cost of transit per mile was diminished, and it was possible to compete successfully with railways. With reference to the Lower Seine he had been struck with the remark of the Author at the end of the Paper, to which Mr. Shelford had already referred. He thought that the charge was rather a grave one. He did not take it personally, because he had to thank the Author for assisting the promoters of the Manchester Ship-Canal in the last eventful fight when the victory was won; but reference had been made to "two abortive attempts," and as Mr. Abernethy and he had to accept any odium that might attach to them, it was perhaps natural that he should endeavour to show that the conclusion drawn in the Paper was not justified. He could bear lightly the charge made by the Author, because he sustained it in conjunction with many other engineers. No less than four Past-Presidents of the Institution gave evidence in favour of the training-walls in question, in addition to the Engineers of the Tyne, the Tees, the Clyde, and other rivers. The Author had referred (p. 35) to the condition of the river before the works were carried out, and stated that "shoals rose so high at Aizier and Villequier that the depth of water over them at high-water spring-tides was about 10 feet, so that only vessels of from 100 to 200 tons could go up the river, and frequently had to wait for a high enough tide. Four days at least were occupied in the voyage between the sea and Rouen; and the perils of navigation were aggravated by the bore." That showed the state of things before the estuary-works were carried out—that vessels of a maximum size of 200 tons took four days to get to Rouen. Further (p. 37) the Author stated the result of the works. "The training-works have effected a very remarkable increase in depth between La Mailleraye and Berville, as indicated by comparing the longitudinal sections of the channel in 1824 and 1875 (Plate 4, Fig. 2). The minimum navigation depth between Havre and Rouen, at high-water neap-tides, has been increased from 10 feet up to 18 feet. Vessels of 2,000 tons can navigate the river; and it has been found possible, under favourable conditions, to bring up a vessel drawing 21 feet. Moreover, the charge for freight between Havre and Rouen has been reduced to one-half, and the rate of insurance for Rouen is the same as for Havre. The trade of Rouen has consequently greatly increased, and it has become the fifth port of France." If the result of the works on the Mersey had been to do as much for Manchester, more could hardly be asked for. Remembering the struggle that

Mr. Williams. he had been engaged in for the past few years, he began to think whether the Author had looked at Havre as being the Liverpool, and at Rouen as being the Manchester of the Seine. The natural inference from that would be that it would be shown in the Paper that Havre, or Honfleur had been damaged; but there was no representation by the Author to that effect. Indeed the very reverse was stated, for there were one or two sentences tending to show that the approach to the port of Havre was rather better now than it was formerly. What principle should be pursued? If a river was designed only for the benefit of some port at its mouth, all sorts of questions might be raised about the equilibrium of the shifting sand-banks and currents; but here there was a positive result, a great benefit to a port inland, and it was certainly a benefit to a country to make such an inland port—the fifth port in France, without damage to any one. The question of accretion was undoubtedly an important one; but still, if accretion occurred, and no damage was done to any existing interest, it was not a very bad thing. The result of accretion in the case of the Seine was remarkably good, for the Author had stated that the land accreted had realized the sum of £1,600,000, which paid for all the expenses of the great river-works that had so benefited Rouen. He thought that any engineer designing those works would naturally expect the accretion that had occurred, as the French engineers had expected it. He admitted that any engineer, on an estuary like the Seine full of silted matter, who raised a training-wall above the level of high-water, and tied that wall into the side-banks in the way that all the Seine training-walls had been tied, made an ordinary and natural trap for the deposit of silt; and on the Dee, where he was engaged in carrying out some works, that result had also followed. Telford, and other engineers who had designed the training-walls on the River Dee, had done so with the avowed object of making accretion, and reclaiming the land; the engineers on the Seine had done the same, and they had achieved their object, and paid for the works out of the land they had made without damage to any one. Another point which the Author had brought out in his Paper (p. 38), was that "The improvement effected in the channel by the training-works has caused a lowering of the low-water at Rouen 2 feet 3½ inches at spring-tides, and 2 feet 9½ inches at neaps; whilst the high-water level has remained unaltered. The tide reaches Rouen fifty-eight minutes earlier than formerly, namely, about two and a quarter hours after high-water at Havre." No better proof could be given of the improvement to the river than that the

works had lowered the low-water level 2 feet 6 inches, on the average, on all tides 74 miles from the sea. As the result of the works, it was estimated by the French engineers, that the scouring of the Seine after the training-walls were completed, had taken out 80,000,000 cubic yards of sand from the upper portion of the river. What did that mean? The estuary of the Seine, measured across from Havre to Honfleur, was about 5 miles in width. The accretion had taken place high on the sand-banks at the mouth. It had displaced tidal-water at a high level which would have ebbed out over a great expanse of open sea 5 miles in width. It would puzzle any engineer to determine what the diminution of the velocity of the current would be across that 5 miles caused by accretion; but any engineer could understand the gain of a drop of 2 feet 6 inches in the low-water level 74 miles above. With water going down late in the tide through the low-water channel, the gain was obvious, and that was a gain similar to what had occurred in the case of the Seine. Mr. Williams.

He next came to the second portion of the question how far the case of the Seine was parallel to that of the Mersey. Even supposing (which the Author had not proved) that the Seine works had been in any way an injury, it did not follow that the Seine and the Mersey were on all fours with each other. In regard to configuration, there were in the Mersey two estuaries, the outer estuary, which would compare with the Seine up to Quillebeuf; then came the "narrows" between Liverpool and Birkenhead, and then the second estuary. In the Manchester Ship-Canal inquiry, the opponents of the scheme always said that it was impossible to compare the Clyde, or the Tyne, or the Tees with the Mersey, which was a peculiar river, and they now adduced the case of the Seine. In fact, the Seine and the Mersey, in regard to configuration, were in no ways comparable, being utterly distinct. If it had been proposed to train the outer portion of the Mersey between the Rock Lighthouse and the bar there might be something in it. But how was it proposed to treat the Mersey? The Upper Estuary would be a good navigation if the low-water channel could be kept in a given line, but it wandered about at random. It had been part of his duty to buoy and light the Upper Estuary for a long period, and a steamer and crew had been kept constantly going about shifting the buoys day and night. When he stated that the navigable channel once shifted 3 miles across the estuary in twelve months the members would understand the present state of things. All that it was proposed to do in the upper portion of the estuary was to confine the forces of

Mr. Williams. nature in one given line. It could not be beneficial that the upper channel should be constantly shifting and sending down material to diminish the depth on the bar. It was not proposed to carry out the works to the high-water level; it was not proposed to carry works to what were called half-tide walls; the height at which the walls were fixed in the Bill was only to the level of the existing sand-banks. That being the case the advocates of the scheme merely retained the low-water channel in one given spot, and prevented what was called fretting. If accretion was to occur with that state of things they must have prevented the powers acting which kept down accretion. What were those powers? No one would deny the effect of currents, but as the training-walls were only to go to the level of the sand-banks there was no interference with the effect of currents passing over them, and as there were sand-banks in the Mersey, particularly one at Eastham, through which the low-water channel had not gone for many years, and that bank had not increased above its ordinary level, it was evident that the natural powers there were sufficient to keep it down to that level. But the question of the power of wind and waves ought not to be lost sight of. The bar at Liverpool was an impediment which varied year by year. The depth at low-water spring-tides had been only 7 feet and at other times 17 feet. What was the power that caused that variable state of things? If there had been 17 feet over the bar in 1885 and it had gone down to 7 feet in 1890, that might have been regarded as the effect of the Manchester Ship-Canal training-walls if they had been constructed meanwhile. But the Upper Mersey Estuary was now left in all its integrity, and yet the bar was shifting and changing. It only showed what Sir John Coode had repeatedly pointed out, that the wind and the waves were the greatest powers in a wide open estuary like the mouth of the Mersey or the mouth of the Seine. The Author had given an interesting Table (Appendix II.), showing the capacity in cubic yards of the portion of the estuary west of Honfleur, corresponding very much with the position of the Liverpool bar, and it would be found that in 1834, long before the works were commenced (in 1853) the capacity was 433,348,000 cubic yards, and in 1869 it was 490,168,000 cubic yards, an increase of nearly sixty million cubic yards. In 1875 it fell to 486,768,000, and in 1880 to 441,628,000. Thus long after the works had been completed, the tidal cubical contents of that portion of the estuary were nine or ten million cubic yards more than in 1834. It was impossible, therefore, from those figures, to draw the conclusion that the works

were the sole cause of the changes outside. It was clearly also a question of winds and waves. It had been stated that the training-walls ought to have been carried out to deep water. There was deep water at Garston, and below Garston there were the narrows. Surely the Author could not have meant that the training-walls should be carried through the narrows, and so on to the sea. They were carried on to a point where large vessels could get to Garston, which was deep water; so that one condition laid down by the Author had been fulfilled. The Liverpool bar had, of course, been a great question in the consideration of the Manchester Ship-Canal. There was virtually no bar on the Seine. Again there was a bore of a formidable character in the Seine, but there was none in the Mersey. He thought it was rather a disgrace to Liverpool that the question of the improvement of the bar had not been dealt with. An eminent engineer, Captain Eads, had been brought from America, who had laid down some good elementary principles on hydraulic engineering, and if Liverpool had kept him for a short time to remove the bar, as he had in the case of the Mississippi, some benefit might have been done to the river. He had been very much struck with some evidence that had been given by Mr. Thomas Stevenson, M. Inst. C.E. He was asked how many rivers he had improved, and he mentioned a large number. He had carried out training-walls, he said, in many of them, and accretion had followed; but it had not interfered with the improvement of the river, or caused shoaling at the bar in any single instance. It was impossible to put the case stronger than that. In conclusion he desired to say that having had occasion to read much on the subject then under consideration, he had found great benefit in studying the Minutes of Proceedings of the Institution, and especially the remarks of those members who had from time to time occupied the chair. There was one point upon which they had been absolutely consistent and unanimous, and that was in the declaration, that in treating of improvements in rivers they ought not to be dogmatic; because no two rivers were alike. Their profession was too grand to be trammelled in any such way. He hoped that the younger members of the Institution would always bear that in mind. All rivers should be studied, and having brought together all their knowledge from actual experience and reading, they would be better able to lay down correct lines for the improvement of a river or an estuary. Mr. Williams.

Mr. J. ABERNETHY, Past President, said that Mr. Leader Williams had ably stated various points to which he had himself intended Mr. Abernethy.

Mr. Abernethy. to refer, and his remarks would therefore be of a more general character. The Paper had been well and carefully drawn up, and the description given by the Author of the works for improving the Upper Seine would no doubt afford most valuable information to the younger members of the profession. The works carried on in the Lower Seine, from Rouen to near Havre, were much on the same lines as similar works carried on in rivers in this country and abroad, and with the same satisfactory results. Much, of course, remained to be done. The training-walls should be carried further seaward, so as to fix the channel from Havre to the sea in one given direction. A great deal had been said with regard to accretion, and it had been stated that it had taken place to such an extent, as absolutely to interfere with the channel seaward of Havre, and that the effect of the improvements in the Upper Seine, from Rouen to the end of the training-walls, had been a manifest injury. It was obvious that accretion must take place, from the enormous quantity of material moved from the bed of the river by the confined current between the training-walls, and that accretion was no doubt deposited upon the banks lying between Honfleur and Havre; in other words, a certain portion of the shallow tidal stream, which ebbed and flowed over those banks, was arrested. And what was the tendency of that? Undoubtedly, to throw a greater volume of water into the proper navigable channel. He knew the Seine forty years ago, when small sloops and barges were the only class of vessels that could reach Rouen, and that only in three or four days. On his visit to Rouen the year before last he found vessels of more than 1,000 tons at the quays, and in going down to Havre he passed a vessel of nearly 2,000 tons, drawing 20 feet of water, proceeding to Rouen. There could, therefore, be no doubt as to the success of the operations so far carried out by the French engineers. He had made a point of inquiring as to the effect of the works upon the channel from Havre seawards, and the general information he had obtained was that they had been rather beneficial than otherwise. He thought that was evident from a passage in the Paper, p. 41: "The time of high-water at Havre has advanced thirty-eight minutes; and the reverse current, which makes its appearance near Havre some time before high-water, has also advanced about thirty minutes. Mr. Lavoinne considers that this change is due to the increase in depth seawards of Havre, and not to the influence of the diminished capacity of the estuary." He quite agreed with that statement. He was rather surprised at the

remark at the end of the Paper with regard to the projected works devised by Mr. Leader Williams and himself in the Mersey. The Author pointed out the great danger of carrying training-walls to the middle of a sandy estuary. That was not the case in the Mersey, the walls were projected through the sandy section to deep water. In the case under consideration although all the works had not been carried out, the result was simply this, that while the navigable channel to Havre had been rather improved, a deep-water communication had been formed with one of the most important cities in France, and a great inland port had been created. Such results reflected the highest credit upon the engineers who designed and carried out the works. Mr. Abernethy.

General Rundall, R.E., observed that he was not personally acquainted with the Seine or any of the works described in the Paper, but there was a similarity in that river to some rivers in other countries; and in regard especially to the phenomena of floods, the experience of those who, like himself, had been in India, might perhaps be of interest. In the section on floods, the Author had stated that, "The occurrence of high floods is due to the concentration of the rainfall at special periods of the year, and not to a high average rainfall throughout the year." To a certain extent on the Seine that might be strictly true, but in tropical countries, where the rainfall was confined to a very short period of the year, a high average rainfall did to a certain extent regulate the extraordinary floods which happened. But there was one point which had not been noticed in the Paper, and to which extraordinary and exceptional floods might be due, namely, the configuration of the basin itself. When the catch-ment-basin of a large river assumed the form of a parallelogram, being long and narrow, if the storm producing the rainfall struck the lower end of such basin and travelled up it, evidently the tributaries at the lower end would run off a greater portion of their volume before the tributaries on the upper part of the river nearer the source were even filled; therefore the flood-volume of the whole basin did not arrive simultaneously at a particular point. In the case of a basin whose length and breadth were more nearly equal, a storm striking the outer part on one side would take some time to travel across to the other, and therefore the floods in those tributaries first affected would commence to contribute their portion, but the distance not being so great that the whole volume could have time to run off, they would arrive at a certain position on the main river, such as Paris on the Seine, more simultaneously. The catchment-basin of the Seine above Paris, which had two General Rundall.

General Rundall.

main tributaries that fed the main river itself, was nearly circular, but suddenly narrowed there, so that if Paris were taken as a centre it resembled a sector of a circle with a radius of 150 or 160 miles. Paris itself was nearly equidistant from the two extremities, and consequently the volume of water which had to run down the tributaries would arrive almost simultaneously at Paris, were it not for other considerations connected with the strata. But supposing a storm to strike the circumference of the Paris basin it would have to travel across to the other side before the whole effect of it would be felt. In the case of cyclones in India it had been found that those storms gyrated on their axes sometimes at the rate of 100 miles an hour, whilst their onward course was at the rate of not more than 10 miles an hour. Consequently if such a storm occurred on the Seine basin it would take fifteen hours to travel across to the other side. If such a thing as a cyclone did occur there, or a very heavy rainfall, he doubted whether the main river could carry the water off at Paris, but fortunately in temperate countries cyclones did not occur, and it was seldom that there was a very heavy fall of rain simultaneously over such an area as even 31,000 square miles. He might be permitted to refer for the sake of comparison to two rivers in India. The basin of one of them, the Mahanuddy, in the province of Orissa, somewhat resembled that of the Seine, but was on a larger scale. It had a course of about 500 miles from its source to the sea, and a basin of 45,000 square miles. A curious feature about it was that its tributaries partook more or less of the same shape as the whole basin. The floods which occurred on that river were very heavy. The Mahanuddy, after collecting all the waters brought by its tributaries, ran through a long and narrow gorge flanked by high hills, and when it arrived at the end of the gorge, it precipitated the whole of its volume on to the delta, where it was carried off by several effluents. When storms occurred which affected only a portion of its tributaries, the rivers in the delta were able to carry them off, but in a great storm, like that in 1866, which travelled across the basin, the delta rivers were not sufficient to carry off the whole volume, and tremendous devastation occurred from the floods, thousands of square miles being inundated. Of late years effective embankments had been constructed, and a great portion of the country formerly liable to be flooded was now protected. The great rainfall in 1866 occasioned a flood which lasted about ten days, and during that time 22,500 million cubic yards were discharged, equivalent to a rainfall of 6 inches over the whole area. After the tenth day, instead of

the river continuing to fall, it began to rise again, and it rose to within 6 inches of the previous level; the duration, however, was only four and a half days, and the total volume of water discharged during that time was about half that in the former flood. The rain that fell was at the rate of 1 inch per day over the whole basin. It was impossible to tell the exact proportion that flowed off, because it was on such a large scale. That case was almost parallel to the instance cited by the Author, of the Seine flood in 1883, as consequent upon two heavy falls of rain following close upon each other. The other river to which he had referred was the Damooda, the shape of which was nearly a parallelogram, whose length was 220 miles, average width 35 miles, and area 7,200 square miles. In 1859, which was a year of exceptional flood, there was a rainfall of 5·50 inches in one part of the basin, varying to 1·80 inch in another part, in twenty-four hours. The character of the river was torrential; it had a slope of 40 feet in 3½ miles, and that slope gradually decreased to 2½ feet per mile when it reached the gauge which recorded the height and fall of the river. The gauge was about 60 miles above the confluence of the Damooda with the Hooghly. The flood reached that gauge in twenty-four hours. Its total duration was three days, but the maximum height lasted only about three hours. The total volume which passed in the three days was 2,500 million cubic yards, equivalent to a flow of rain of 4·10 inches off the whole area; whilst the total rainfall, as far as it could be ascertained, was about 11·10 inches over the basin. The rain-gauges, however, were too few in number to enable any accurate inferences to be deduced, so that when averages of rainfall were spoken of as regulating floods, it was necessary to be cautious in ascertaining how far they had been obtained from a sufficient number of gauges. As to the prediction of floods by the heights of tributaries feeding the main river, he did not think that that would be practicable in India, because the sources of these large rivers lay in uninhabited forest tracts of a deadly character, so that there was no possibility of ascertaining the height of the tributaries. But on the large rivers, like the Mahanuddy, there was telegraphic communication, so that it was possible to know when the maximum flood was passing certain points, and when it might be expected at the head of the delta, which was the crucial point of the river. The question of wave-propagation was an interesting one, but it had not yet been well worked out. He was surprised to find from the Paper that the speed of the wave of propagation on the Upper Seine was 5·72 miles an hour, as the rate of its travelling from

General Rundall.

General Rundall. the extreme point Clamecy to Mantes, 228 miles, ranged from 2·00 to 2·21 miles per hour, which seemed to correspond to what had been observed in India. The Paper would no doubt be useful to engineers in India, though the works carried out on the Seine were not generally applicable to India, because the sectional-area of the beds of the rivers in dry weather was so very large in proportion to the actual water-section; and works that could be carried out on a river like the Seine—on the Upper Seine and down toward the tidal reaches—could in very few instances be adopted in India. But engineers in India had been glad to take advantage of some of the patterns of weirs that had been executed on the Seine, with certain modifications which local circumstances required. They had built them in the large dams to act as scouring sluices, and they had been found to answer exceedingly well. He looked upon that section of the Paper, which treated of internal navigation, as a most important part of it; for it appeared to him germane to some questions of the present day in England. A great deal had been said about preferential railway rates as bearing so hardly on the trading and commercial community generally, so, as he had said elsewhere, he thought it was a great pity that England did not revert to her old national mode of water-carriage. There was room for both rail- and water-transport, and if England only followed the lead of the Continent in that matter she would act wisely. He had taken great interest in Mr. Leader Williams' project for the Manchester Canal, as in all other canals that had been mooted in England and elsewhere. One of the great features of the day was the National Conference at Brussels last year, which he believed was to be renewed this year at Vienna. If the magnificent projects which had been suggested in that conference should ever be brought about they would revolutionize the question of carriage throughout Europe.

Mr. Owen. Mr. G. Wells Owen observed that the Author, in Appendix III., with reference to the changes in the Seine Estuary, between 1875 and 1880, had given some statistics of the amount of accretion and erosion that had occurred in different parts of the estuary in that period. For the purpose of taking the quantities, the engineers had divided the river into sections, the first section commencing at the end of the training-walls, at Berville, and extending 2,200 toises, or about $2\frac{1}{2}$ miles down the river, the remaining sections being each 1,000 toises, or $1\frac{1}{5}$ mile in length. It was often said that anything could be proved by statistics, and he wished to make a few observations upon this Appendix with a view of preventing wrong inferences being drawn from the

statistics in question. It was stated that in the first section of the river there had been nearly 2,000,000 cubic yards of accretion. That statement, standing by itself, was of no value without cross-sections to show where the accretion occurred, and from the survey of 1880, and as might be expected, it was manifest that all that accretion had taken place on the high banks, outside the line of the training-walls, and not in the channel itself, where there would be a considerable amount of erosion and deepening. In the next five sections it was admitted that there was erosion and deepening, and the result was that for 8¾ miles below the training-walls the channel had been deepened and improved. That he thought would tend to show that however desirable it might be to carry the training-walls, as shown on the plans, down into the estuary and into deep water for the purpose of preserving the ports of Havre and Honfleur, for the mere purpose of improving the channel into deep water, it was not necessary to carry training-walls the whole way, but that the channel would be deepened the whole way if the training-walls were taken some few miles farther only than they existed at present. It was also stated at the end of this Appendix: "Accordingly the volume of accretion, between 1875 and 1880, amounts to over 40 million cubic yards." He had considered the figures given in the Appendix in every possible way, but was unable to arrive at the 40,000,000 in any shape; he would therefore ask the Author carefully to consider the quantities quoted from Mr. Germain's report, and to give some explanation as to how that quantity had been arrived at. The Author also quoted from the same source: "Taking the divisions separately, instead of their sum, it appears from the above Table that accretion occurred in the wide division next the training-walls" (he had already pointed out that although there was accretion there, in all probability it was not in the channel itself); "then erosion in the next three divisions, followed by accretion in all the other divisions except the last." Whereas in the Table it appeared that there was erosion in the next five divisions, and then accretion in all the other divisions. He would ask the Author to reconsider this statement. Mr. Owen.

Mr. J. N. Shoolbred said he would make a few remarks on the part of the Paper relating to the Estuary and to the tidal portion of the river; not merely because he had had a long acquaintance with the Seine, but because circumstances had enabled him to obtain information, which he thought would be interesting to the members. Eight or nine years ago, as the Secretary of a tidal committee of the British Association for the Advancement of Science, Mr. Shoolbred.

Mr. Shoolbred. charged with obtaining certain tidal observations in the English Channel, he was, by the permission of the French Minister of Public Works, placed in communication for that purpose with a number of Government engineers round the coast, at Havre, and several other places; and since that time he had been in receipt of certain official information, some of which, he thought, would be useful in connection with the Paper. From the Paper under discussion, a good idea could be formed of the history of the construction of the so-called walls, but which were mere mounds of rubble-stone. With regard, however, to the magnitude of the operations and changes which had been, and were being wrought by nature, principally through the disturbing influence of those training-walls, he did not consider that the information given in the Paper was sufficient to enable a due appreciation to be formed, on several points, as to the magnitude of the resultant effects.

The longitudinal section (Plate 4, Fig. 2) of the part of the river from La Mailleraye to the sea, was in his opinion liable to convey an impression of a most marked improvement having taken place, not merely in the deepening of the bed, but also in the general condition of the river since 1824. That longitudinal section should, he considered, have been extended up to Rouen, near to the head of the tidal establishment of the river, as was shown in the one submitted by himself (Plate 5, Fig. 13). It would there be seen, that in the upper part there had been no similar artificial deepening of the river-bed. In fact, the excrescence in the river-bed, in 1824 and until 1853, between La Mailleraye and the sea, must have had the effect of a huge dam in penning in the water between La Mailleraye and Rouen. The effect upon the tidal-action, consequent upon the removal of this dam, was detailed, in part in the Paper. But to understand the changes more fully, there should be shown upon the longitudinal section of the river a comparison of the high-water and the low-water levels respectively, before as well as after the lowering of the river-bed (Plate 5, Fig. 13). It would be there seen, amongst other matters, that the ebbing tide, from the upper part of the river, had before the dredging been practically dammed back until reaching Tancarville, almost at the Estuary itself; into which it then poured down a steep incline, and consequently with very considerable scouring-power. Now, however, since the lowering had been effected, the discharge of the tide took place over a much gentler and more lengthy incline, and practically with the same head from La Mailleraye, instead of from Tancarville. The distance in the latter case to Berville

being but 7 miles, as against 28 miles in the former case. No accurate estimate of the state of the river could be formed from the longitudinal-section alone, without taking into consideration the cross-section thereof at various points. Mr. Shoolbred.

A series of comparative cross-sections of the river, extending from La Roque to La Mailleraye, were taken by the engineers of the French Government in 1850, and again in 1867; before the commencement, and after the completion, of the river walls. A certain number of these, taken from the more important ones, were shown as sections D, E, F, G, and H, and were shown in Plate 5, Figs. 8, 9, 10, 11 and 12. There were also shown some other sections A, B, C, Figs. 5, 6 and 7, extending at intervals down the Estuary from the termination of the river walls to the neighbourhood of Havre. The periods of comparison for these estuary sections were 1863, shortly before the completion of the river-walls, and 1880, the last complete survey of the Estuary. He himself had compiled these estuary cross-sections from official documents of the French Government. An examination of all these cross-sections, taken in conjunction with the longitudinal-section, showed that, owing to the enormous accretions between La Roque and La Mailleraye, amounting to over 20,000 acres, the amount of tidal-water now discharged from the river on the ebb-tide was about one-third less than before the works were commenced. While, again taking into account the diminished and at the same lengthened incline down which this reduced amount was discharged, it might be roughly estimated that the scouring-power of the tidal-discharge at Berville now was only about one-sixth of what it had been previous to 1850. With so considerable a diminution in the scouring-power at the upper end of the bay, it could readily be understood how those enormous accumulations, covering at least 35,000 acres, had been caused in the Outer Estuary. It was, as even Mr. Leader Williams had pointed out, only after the completion of the river-walls, that the improvement in the seaward portion of the Estuary had ceased; as evidenced by the relative position of the contour-lines, of the deep-water soundings, visible on the charts between 1834 and 1875. From the latter date to the present time the position of these contour-lines had steadily, and at times rapidly, receded seawards. Between 1875 and 1880, the 10-metre contour-line (below the "Zero des Cartes Marines") receded seawards $2\frac{3}{4}$ miles; the 5-metre contour $1\frac{3}{4}$ mile, and the 3-metre contour $1\frac{2}{3}$ mile.

The Author had shown in Appendix II, on the authority of Mr. Lavoinne and of Mr. Vauthier, that the low-water area of

Mr. Shoolbred. the Estuary had been decreasing steadily since 1875; by which date the diminished scouring-power of the river began to be felt in the Estuary. But the most serious of the various results was that now going on in the immediate vicinity of the port of Havre, between the Amfard Bank and the entrance to the port, and westward of the Hoc Point. The accumulations in that region were, during the period 1875–80, at the annual rate of 6,500,000 cubic yards, while between 1880 and 1883, that rate had increased to 9,000,000 cubic yards per annum. Thus during the decade 1875 to 1885 at least 60,000,000 cubic yards had been deposited almost at the very entrance to the port of Havre; and at a rate of deposit which threatened to close entirely the entrance to that important and flourishing port. This was the price which France was now paying for the improvement in the navigation of the Seine up to Rouen and for making that city into the fifth port of that country. In doing this, France was sacrificing Havre, its second port; and one which was of far more importance to that country, and to Northern Europe than Rouen was, or ever could hope to be. Yet, with these facts before them, some of the speakers, Mr. Leader Williams among the number, would fain inquire, Where was the damage to the Estuary of the Seine, arising from the works undertaken for the improvement of the river up to Rouen?

It seemed to be admitted on all sides, in France as well as in this country, that the river-walls on the Seine must be extended seawards to the mouth of the Estuary. Several proposals had been made from time to time, but that suggestion which appeared to find most favour in France was the one of the late Mr. Lavoinne, who occupied at the time of his death, and had done so for some years previously, the post of Chief Engineer in charge of the Seine between Rouen and the sea. He was well fitted, therefore, from his position, from his personal qualifications, and from his intimate knowledge of the subject, to form a practical scheme for the extension of the walls. The Author had put forth in the Paper a proposal of his own. The course of his northern wall there indicated might be said to be identical with that of Mr. Lavoinne —indeed the course taken of late years by the sea-face of the accumulations in the Estuary, as well as the set of the flow and of the ebb of the tidal-current of River Seine, almost indicated the convex form and also the direction of this northern wall. But it was in the seaward extremity of the extension of the southern wall that the Author differed from Mr. Lavoinne. Westward of Honfleur, the former followed the low-water line, which was

pretty permanent, round the coast to Trouville. While Mr. Lavoinne's scheme extended from Honfleur westward into the bay, taking advantage of a ridge of rocks, up to a well-known shoal called the Ratier. His object being to form a breakwater for the interception of the tide-borne detritus, coming from the coast of Calvados and the south-west, and thus to prevent an accumulation of deposit in his newly-regulated entrance-channel to the Seine. The absence of any such precaution in the Author's plan was a serious objection to it; indeed there seemed nothing in his scheme to prevent the continuance of the deposits, as at present, on the southern face of the proposed northern wall. The depositing ground, or catchment-basin, clearly intended by Mr. Lavoinne, was the space between Villerville and the Ratier shoal. It was also very doubtful whether a deposit there formed would ever, as the Author feared, jeopardize the approach to Trouville, since the tidal-current from the south-west would, when the bank of accumulations extended sufficiently seaward, probably sweep on from Trouville and past the seaward end of the Ratier shoal without leaving any deposit. He strongly approved of this part of Mr. Lavoinne's proposal, in contradistinction to that of the Author. Mr. Shoolbred.

Inferences had been attempted to be drawn from the above-described operations as to the effect of training-walls upon the Upper Estuary of the Mersey, and the want of similarity of the latter river with the tidal-portion of the River Seine. In such a comparison, however, the present condition of the Mersey, untampered with in the Upper Estuary, should be compared with that of the Seine in 1834 and up to 1850, before the construction of the river-walls (Plate 5, Fig. 1); not with its present mutilated condition, as the comparison was usually made. The conformation of the Seine, in its reaches immediately above the Estuary, would be found, at the earlier date, to present much closer points of analogy with the Upper Estuary of the Mersey than the advocates of training-walls in the Mersey would possibly like to admit.

In his opinion the results arising from the construction of the river-walls on the Seine (results most unfortunate, on the whole, and increasingly so each year) were of a most instructive character to engineers. They pointed out most unmistakably, how ill-judged it was, in tidal matters, to disturb violently the balance of forces which nature had established; and also, how difficult it was—nay, almost impossible, as evidenced by the later efforts of the French engineers—to re-establish that balance, once it was destroyed.

One word on the subject of movable weirs. It was noteworthy,

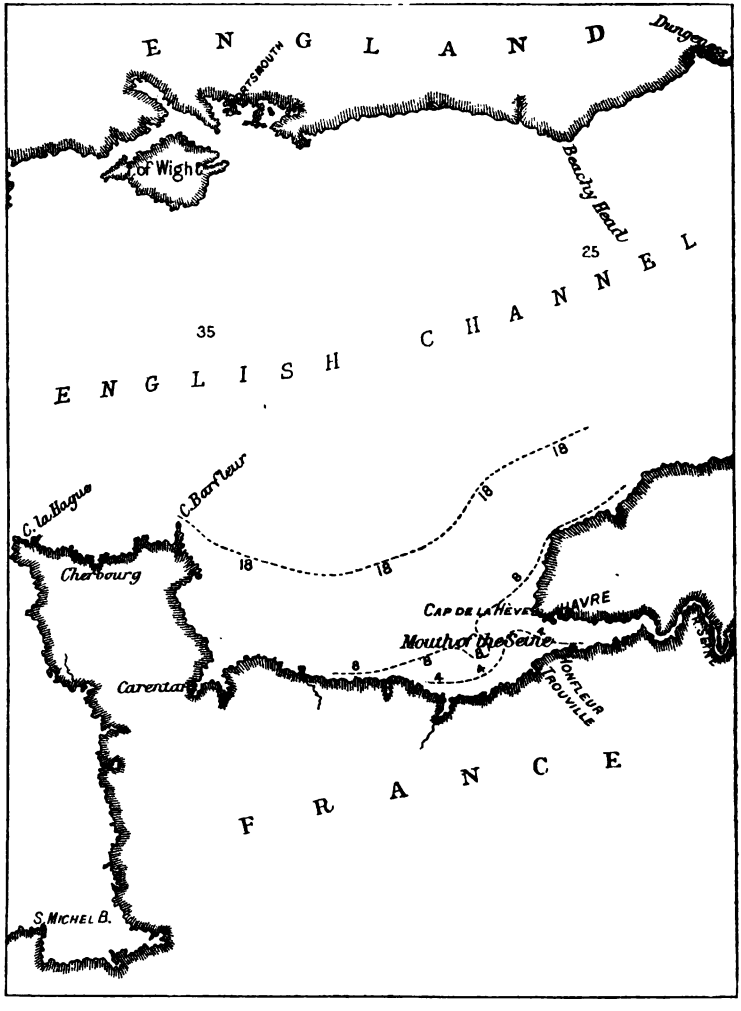
Mr. Shoolbred. in actual practice, to observe the clumsy and tedious operation of the needle-weirs, on the Seine. Take the one at Martot for example. Contrast it with the tilting-weirs of Mr. F. Wiswall on the Irwell, near Manchester, and on the Upper Mersey, and which the Author had briefly referred to. In the former case, each needle was separately removed by hand, over the stream itself, along a foot-bridge, which remained in floods as a permanent obstruction; while in the latter, the tilting-gates were all controlled and worked from the banks. Furthermore, in case of floods, the gates, if not already opened, were automatically tilted over by the increased weight of water, leaving an unimpeded water-way across the entire width of the river, save for the slight obstruction of the cast-iron supporting-frames of the gates. The saving of time in opening or shutting the respective weirs must be immensely in favour of the tilting-weir.

Sir James Douglass. Sir JAMES N. DOUGLASS said the Paper was especially valuable as recording another instance of the efficiency of training-walls. Sir James Douglass had had nineteen years' intimate knowledge of the Seine Estuary, and he entirely agreed with the Author in the opinion that the extension of the training-walls was necessary, if a deep-water channel from the sea was to be maintained. The proposals for the improvement of the entrance were very conflicting. It was first demanded that deep water should be preserved at Havre, and next that deep water should be preserved at Honfleur; and at the same time it was expected that no accretion should occur at Trouville. That, however, was nearly impossible. All would agree with Mr. Leader Williams that it was a difficult matter to compare any two rivers, and he believed that the question had hitherto been discussed without really considering the main point, namely the connection of the Seine with the sea. Fig. 3 represented the Seine in its relation to the English Channel, from which it would be seen that the direction of the discharge of the Seine was exceedingly unfortunate. It discharged in a direction nearly parallel to the coast; it had in advance and opposed to it the land trending out to the northward, and terminating in Cape Barfleur, which necessarily caused a shallowing in the elongated bay into which the Estuary opened, because it interfered with the tidal-current and prevented the scour that would otherwise occur. Again, the Seine delivered in the face of the travel of the eroded material of the coast to the west of it. It was well known that a very considerable quantity of material was delivered on the southern area of the estuary, as shown on the present charts. In an old chart, made from surveys taken in

Sir James Douglass.

1776, it was shown that the deep water at that time was in front of Honfleur. Where it was then 9 fathoms it was at the present time only 2½ fathoms. Since that time the deep water had been

FIG. 3.

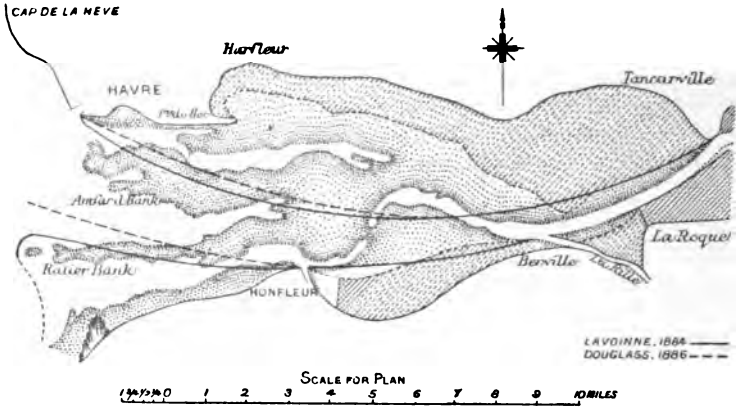



trending to the northward, and now it would be found by recent charts that the deep water was in the centre of the estuary, or nearly midway between Havre and Honfleur. Hence it might be concluded that the training-walls should be carried on nearly in

Sir James Douglass.

the direction indicated by Mr. Lavoinne, as shown in Fig. 4, the modifications he would suggest were shown in dotted lines. Evidence had been given that a very large amount of material had been brought down and deposited. Where was it to go? There was ample room for it in the Channel if it could only be carried there by narrowing the estuary. In doing so no doubt some accre-

FIG. 4.




tion would follow at Trouville; but surely that was a secondary question as compared with the maintenance of deep water up to Havre, Honfleur and Rouen. He contemplated no difficulty in the problem, nor had he any doubt as to ultimate success. Not only would deep water be maintained, but nothing more would be heard of bores in the Seine.

Mr. Pember.

Mr. E. H. PEMBER, Q.C., would not venture to give any opinion of his own upon the scientific questions involved in the discussion, but perhaps an unscientific by-stander might sometimes catch a point from hearing what was said on both sides. The remark of a previous speaker, who stated that he had had many years' knowledge of the Seine, had suggested to him what indeed had occurred to him more than once during the discussion on the Manchester Ship-Canal scheme, that the analogy between the Seine and the Mersey, when applied to the case of Liverpool, failed in one important point. Havre was not in a position on the Seine in any degree analogous to the position of Liverpool upon the Mersey. If there was one place on the Estuary of the Mersey which was analogous to the position of Havre on the Seine it was Formby, which was a very long way

beyond Liverpool. Liverpool was placed upon the Mersey at a point which would be represented by some position to the north of Berville, on one of the lines representing training-walls or their prolongation. That appeared to afford food for considerable reflection in dealing with the question as a practical one. If the training-walls, whether prolonged to the point suggested by the Author, or stopping where they now did on the Seine, reduced the tidal-capacity to an enormous extent without interfering with the main sea-passage up into the river, or with the inland navigation, it appeared to him that, unless there happened to be a port on the Mersey in a bight, as Havre was on the Seine, it might be that no harm would be done by similar works on the Mersey. There might be any amount of accretion upon the Mersey, for instance, in the direction of Formby, but if it did not interfere with the sea-approach up in the direction of Manchester and Liverpool no harm would be done by it. If a lesson were to be learned from the Seine, and applied to the problem of the Mersey, the question would have to be answered, either in the affirmative or in the negative—had the works carried on upon the Seine injured the main sea-approaches into the Estuary? He had never heard that they had injured them. He had often consulted French pamphlets on the subject published by authority; and although a great deal had been said about the accretion in the neighbourhood of Havre, and also, he believed, in the neighbourhood of Honfleur, nothing had been said about the approaches to the river itself having been injured in any way. Mr. Shoolbred had stated that the price which France was paying for the improvement of her fifth port, Rouen, was the practical extinction of her second port, Havre. It might be true that Havre was damaged by the works carried out for the benefit of Rouen, but there was nothing in that analogous to damaging Liverpool by carrying out the proposed works on the Mersey. After all the question came to this, had anything occurred on the Seine, in consequence of the training-walls, analogous either to an injury to the Mersey Bar or to the approaches to Liverpool? The answer was, so far as he recollected the documents, that nothing had been done which was analogous to either of those things on the Seine. It had been proved to demonstration that the tidal-capacity of the Mersey had varied enormously within the last two decades. It had fallen since 1861 from upwards of 970,000,000 cubic yards to about 950,000,000 cubic yards, and it had risen to 960,000,000 cubic yards in 1881. That showed a decrease of between 20,000,000 and 30,000,000 cubic yards in the first decade, and a rise of

Mr. Pember.

Mr. Pember. 8,000,000 or 10,000,000 cubic yards at the end of the second decade. During that period of twenty years it was proved to demonstration that the height of the bar had varied, and by no means in proportion to the variation in the cubical capacity of the river; in other words, that the cubical capacity of the river by natural causes had gone down very much, while the bar had not increased, but had perhaps diminished; and, on the other hand, the cubical capacity had gone up again, whereas the bar had not varied in the direction of improvement, or at all events in the same proportion. He ventured, therefore, with the greatest deference, to suggest that up to the present time two things seemed to be in great uncertainty: First, whether, after all, the cubical capacity of an estuary had really that direct effect upon a bar at its mouth which some engineers thought it had; and secondly, whether any effect had been caused by the works upon the Seine analogous to the damage of the bar on the Mersey, or to any port in the position of Liverpool.

Mr. Taunton. Mr. J. H. TAUNTON observed that as reference had been made by the Author to the Thames, the Metropolitan river, and as some slight comparison had been instituted between that river and the corresponding river of France, he wished to make a few remarks on the subject of inland navigation upon them as treated in the two countries. Before doing so he would consider how far the two rivers assimilated, and how far they differed. Undoubtedly the French river was much the larger of the two, its drainage-area being 30,370 square miles, and that of the Thames 5,172 square miles. The daily summer flow at Paris was 3,333,000,000 gallons as against 400,000,000 or 500,000,000 gallons in the case of the Thames at Teddington. The length from Montereau to St. Aubin was 197 miles, with a fall of 150 feet, and twenty-one or twenty-two locks. From Lechlade, to which point the Thames had been navigable from time immemorial (but where it had been rendered unnavigable by the Board of Conservancy, whose duty it was to take care of the navigation), to Teddington the distance was 126 miles, the fall being 220 feet, and the number of locks thirty-nine. The geological conditions of the two rivers were remarkably similar; they both passed largely through the upper beds of the Secondary strata and through the Tertiary strata, in consequence of which there was a great deal of permeable ground, as had been shown by the Author, and there was a still larger proportionate quantity of permeable ground in the basin of the Thames, which rose mainly in the Cotswold district amongst the loose rocks of the Oolites, the waters being maintained by the Lias

and partly by the Fuller's Earth, and passing through highly permeable strata; hence there was not in the Thames the same torrential character as in the case of the Seine due to the Marne and the Yonne. The affluents of the Seine rose from a source, 2,960 feet above the sea, while in the Thames nothing came from above 700 feet. The Author had stated what had been done for the navigation in France, and it would be well to consider what had been done for the navigation in England. In 1866, in consequence of the bad condition of the Thames, an Act of Parliament was passed creating a new Board of Conservancy, and giving fresh powers for the maintenance of the navigation. Funds were also created, which were now somewhat large. The Board at present received upwards of £12,000 a year from the Water Companies of London alone, in addition to the tolls, and the total annual amount received for the maintenance of the upper navigation was above £17,000; but what had the Board done? In the first place, between Lechlade and Oxford in 1866 there was something of a navigation; there were some old movable weirs of a very primitive construction, but serving the purpose required, enabling boats to travel down the river from the canals joining the Upper Thames, and to reach London. Those boats brought, amongst other things, a great quantity of stone used for the Houses of Parliament. The weirs, which it was true were of a prehistoric nature, but were still of service, had all been removed by the Conservators, who took credit to themselves for having done so, and at the present time that part of the river was not navigable at all. He had himself a steam-launch for many years which he had run upon the river between London and Gloucestershire, and he had always found the greatest difficulty and some risk in passing as far as Oxford, in that it took him as long to get to Oxford as it did to get from Oxford to London. That state of things certainly was not satisfactory, and to add to it a new government had been instituted in connection with the Thames—that of the Thames Drainage Commissioners, who had powers over the river extending to somewhere near Clifton Hampden. Probably they were doing a useful work in supplying funds to the Thames Conservators, but in regard to the interests of the navigation the public would feel much happier if the arrangement led to some result, which up to the present time it had not done. There was a very loud outcry that a navigation which had existed for so many years—from the time of the Conquest—and in respect of which legislation had taken place in the time of King John, should have fallen into desuetude. It was not for want of funds, because funds existed, and erec-

Mr. Taunton.

Mr. Taunton. tions of a sufficiently serviceable character might easily be made so as to keep up some continuity in the Thames navigation. It was not for want of water. At Teddington, where there was a discharge of 450,000,000 gallons a day, one of the large locks described by the Author (197 feet long by 27 feet by 9½ feet, giving a capacity of 50,530 cubic feet), would be filled in a minute; at Oxford it would be filled in four and a half minutes, and even at Lechlade, where there was a discharge of about 20,000,000 gallons a day, it could be filled in twenty-two minutes, so that three locks might be filled in an hour. Of course the Thames locks would not be of that magnitude, but if they were of a sufficient magnitude to float barges carrying 100 tons, that would amply fulfil the purpose required. Many efforts had been made to re-open the navigation, to induce the Thames Conservators to do what it was their manifest and appointed duty to do, and as the Institution of Civil Engineers was to some extent a representative body, he hoped the discussion of the subject by its members would lead to something being done for the resurrection of the old Thames navigation. As to the floods on the Seine, between 1872 and 1884, occurring during the cold season, although the rainfall was then less than in the summer months, he thought that in those results would be found a confirmation of the views of the late Mr. Charles Greaves, M. Inst. C.E., who in his Paper "On evaporation and on percolation" said: "The yield of springs, or the abundance of water in a river, where the river is fed from springs, will be found, from a comparison of the tables .... to be dependent more closely on percolation through the soil than on the mere rainfall; indeed it will be found to correspond with percolation. For, whereas the variations in annual rainfall are as 2·33 to 1 ..... the annual percolation through ground varies as 3·5 to 1."[1] He thought that was an experience to be met with not only in the Seine but in all rivers in similar latitudes.

Mr. Giles. Mr. A. GILES, M.P., thought that the chief interest of the Paper to marine engineers would be found in its reference to the entrance to the Seine at Havre. As to training-walls, it was only to be expected that the erection of such walls as those described would have the effect of scouring out the channel and vastly improving the navigation in the upper reaches of the river. That was pretty well shown by the section in Plate 4, Fig. 2, where the upper line indicated the old bed of the river before the training-walls were put in, and the lower dark line showed the improvement in the

[1] Minutes of Proceedings Inst. C.E., vol. xlv. p. 24.

river-bed since the erection of the training-walls. The Author had stated that there were some very ingenious weirs on the upper portion of the river, and that floods could be predicted, so that the attendants at the weirs could be always ready to provide for them. He could only say that although it might be very desirable to predict a flood (which it appeared was four days in coming down from the upper to the lower reaches), he thought that with all the engineering science and invention of the present day there ought to be no attention necessary to alter a weir, his belief being that weirs might and would be made self-acting. A great deal had been done, as far as he could judge, by putting parallel training-walls along the Seine; but in looking at the plan from Havre to La Mailleraye, he thought that if the French engineers had devoted some of their surplus funds to cutting off the bends and making the channel more direct, it would have helped the navigation. It was evident that the training-walls, when raised to a height shown on the sections, must have the effect of reclaiming the land behind them, and that was indicated by the dotted lines. The Author had stated (p. 45) that: "The modifications needed in the width between the training-walls of the Seine will serve as a useful warning to prevent the tidal-flow of the Ribble from being similarly curtailed." The Author had not stated what those modifications were, but the inference appeared to be that the training-walls were perhaps too close together. He had also stated that the training-walls, carried out as they were in the river opposite Lytham, would only cause a sand-bank to accumulate at the foot of them, and that they must be carried farther. Mr. Giles agreed that they would have to be carried farther; but it was well known that when a Bill was being got through Parliament, it was not always desirable to indicate the work to the fullest extent. The Midland Railway was a case in point. It was not completed as a whole; it began in the Midlands, first getting its head and then its tail, and now it was one of the most magnificent systems of railways in the kingdom. So, in the case of the Ribble, when the works carried out were found to be successful, there would be no difficulty in carrying them farther. With reference to the mouth of the Seine, he thought that the French engineers were aiming at too much. He did not think it possible, however the training-walls were built, with the small volume of water coming down the Seine, to serve the ports of Havre and Honfleur with the same walls. It could only be done by bringing a curved channel, the hollow part of which should touch Honfleur, and then carrying the same curved channel almost opposite Havre. In that

Mr. Giles.

Mr. Giles. way there would be deep water opposite Honfleur, and also at Havre; but then Trouville would be sacrificed, because there could be no doubt that if training-walls were put from Honfleur in the direction of Havre, all the estuary to the west of Honfleur must gradually silt up. He was sorry to find that the Mersey had been dragged into the discussion, but he thought that those who represented the interests of the Manchester Ship-Canal should be able to defend what they had defended for two years in Parliament. He would assume, for the sake of illustration, that the bed of the great Estuary of the Mersey, called the Bottle above the neck opposite Liverpool, should be of solid rock, in which case he maintained that if the channel, as designed for the Manchester Ship-Canal, had been cut through the middle of the rock, without any training-walls whatever, that estuary would no more have silted up after the cut than it did before. He could understand the fear that if training-walls were put above the level of the sands at the sides of the cut, there would inevitably be reclamation and accretion. He never went farther than this, that if a cut were made, it should be protected in that soft material by walls, but those walls should not go above the level of the sand adjoining. He might cite Southport as an instance in point. It would be seen in the map that opposite Southport there was a spot called the Bog Hole. Formerly a channel of the River Ribble went through the Bog Hole, and when this was open, at low-water, the channel had a depth of 3 or 4 fathoms. The channel had been closed for some years with sand; yet the hole was now 6 or 7 fathoms deep. He did not think it could be argued from that circumstance that the channel was necessary to keep the hole open, since it was deeper without the channel than before.

Mr. Redman. Mr. J. B. REDMAN had intended to institute a comparison between the two national rivers of France and England, but he had been anticipated by Mr. Taunton with regard to the upper portions of the rivers. Although the rivers had many features in common, they had also some features that were very widely different. The main channel of the Seine, exclusive of its tributaries, was about double the length of the Thames, 400 miles as compared with 200; the area of the catchment-basin of the Seine was six times that of the Thames, 30,000 square miles, as compared with 5,000, and, excluding the permeable strata, it was about quadruple, 22,000 square miles. The volume of land-water passing through Paris, as compared with that passing through London, was proportionate; but then it should be remembered that London was situated upon a big tideway, while the tide fell short of reaching

Paris by several miles. But even in Paris the river, like the Thames in London, had broken through restraint, for quite recently, in endeavouring to obtain an easier bed for its channel, it had undermined some of the foundations of the historic bridge, the "Pont Neuf." The Author had glanced slightly at the necessity hereafter of increasing the Parisian channel by enlarging the bridges, and Mr. Redman thought that a further enlargement might yet be brought before the consideration of the French Government, not only an enlargement of the bridges, but an elongation. In order to do that it would be necessary to set back one of the embankments of the Seine through Paris, and every one acquainted with Paris would know that the breadth of the Seine quays was excessive as compared with the channel between them. A similar action had been displayed on the Thames only a few years ago, in undermining the foundations of the old bridges at Westminster and Blackfriars. He would next direct attention to the very diverse condition of the tidal portion of the Seine, as compared with that of the Thames. Not only was it diverse, but it was absolutely the reverse. The tidal length of the Seine, 60 miles, was ~~two-sixths~~ one seventh of the entire length of the river; the tidal length of the Thames, 66 miles, was one-third the length of the river. The tidal oscillation of the Thames in London was 25 per cent. greater than in the estuary, 20 feet as compared with 16 feet; the tidal oscillation at the outfall of the Seine was twice the tidal oscillation at Rouen, 20 feet as compared with 10. The surface of the water at low-water in London was considerably lower than it was in the Estuary with certain tides; the surface of the low-water in the Seine at Rouen was 10 feet higher. The surface of the water at high-water in Westminster was from 4 to 5 feet higher than at Sheerness; the surface of the water at Rouen at high-water, as compared with Havre, was identical according to the Author's diagrams, Plate 4, which he had no doubt were correct. The tidal oscillation of the Thames, as compared with the Seine, showed that the first was in a progressive condition, and that in the last it was in a stagnant condition, and there was no need to go far to seek the cause. In the approaches to the Thames, and in the lower reaches of the river, there was a minimum depth of 20 feet at low-water spring-tides over the shoals, but the Seine Estuary at low-water practically ran dry. Mr. Vauthier, the French engineer, in his report upon the Estuary of the Seine, and the port of Rouen, had quoted some figures from a Paper read by him in 1877 on "The River Thames"; giving the elevation at high-water in London as 4 feet above the same high-water in the Estuary, which Mr. Vauthier regarded as a

Mr. Redman.

Mr. Redman. very remarkable result, and no doubt it was so to an engineer specially acquainted with the Seine. Mr. Vauthier had described him in the report as the Engineer having charge of the river Thames; he had certainly never told him so, nor could such an inference be drawn from his Paper, but perhaps it was assumed from the fact that he had brought forward statistics on the subject. As everything in France was to a certain extent official, it was probably thought that he must have some official connection with the Thames. Comparing the two estuaries, the anomaly was that the offing depth in the sea was as great opposite to the Estuary of the Seine, as it was opposite the Estuary of the Thames; the tidal rise at Havre was considerably greater, 20 feet as compared with 16 feet at Sheerness. In a discussion on a Paper read a few years ago by the Author upon tidal harbours intersecting the continental seaboard of the English Channel, and North Sea, of France, Belgium, and the Flemish countries, Mr. Redman ventured an opinion that the outfalls of those tidal harbours were as much affected by the flood as by the ebb, and that accretion on either side of the harbours arose as much from the tidal currents as from the wind-waves. He was then met by the objection from Sir John Coode, that it could hardly be so because the force of the sea-wave was fifty times that of the tidal-current. But thirty years ago he had read a Paper on the South Coast of England, and ten years later another Paper on the East Coast, in both of which he had shown that the great motor in moving the shingle deposits that lined the coasts, was the wind-wave. All along the continental seaboard of the English Channel, and the North Sea, the littoral detritus was entirely different; it was a white flocculent sand easily acted upon by the tidal-currents. The tidal-currents were constant; the action of the wind-wave was intermittent, and doubtless the detritus was as much acted upon by the tidal-currents as by the wind-waves. Sir James Douglass had referred to the influence of the promontory of La Manche upon the Estuary of the Seine, and had described the manner in which that promontory arrested the detritus travelling to the westward, but he did not refer to the remarkable tidal results produced by that peninsula, with which, no doubt, he was thoroughly acquainted. La Manche, 50 miles west of the Estuary of the Seine, projected 25 miles almost at right-angles to the general trend of the coast eastward; it projected almost like a natural groyne or pier, and it had a similar effect upon the French coast, as the Isle of Wight had upon the English coast. After high-water, when the tide set to the westward, it was dammed back by La

Manche to Havre. Havre, like Southampton, enjoyed a period of from two to three hours of still-water, which was, of course, very advantageous for docking and undocking vessels[1]; but it was very promotive of the deposits of detritus in the Estuary of the Seine. The Estuary of the Thames on the contrary, projected in such a form that it received the tide from the North Sea, and from the English Channel; there was a period of suspense of only twenty minutes, or half-an-hour, after high-water; the ebb-tide then bifurcated northwards to the North Sea, and south-west to the English Channel, and there was not the same time for the promotion of deposit. He cordially endorsed the remark of Mr. Leader Williams that, apart from the mere question of engineering, the study of a river was most interesting and fascinating. Dr. Robinson in the article on rivers in his "Mechanical Philosophy" spoke of the manner in which the ancients showed their indebtedness to rivers by absolutely deifying them and giving to each a presiding divinity. And the action of rivers, the circulation of the waters, the evaporation from the ocean, the condensation of the clouds, the distillation of rain, and the return by river channels, had been alluded to in a few terse words by a great eastern poet nearly three thousand years ago; he referred to Ecclesiastes, ch. i., v. 7. "All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again." Mr. Redman.

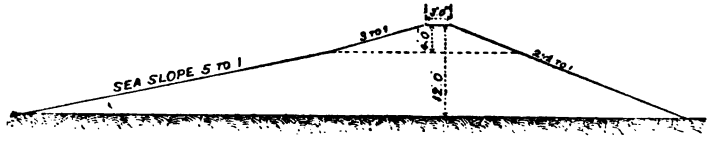
Mr. Charles Douglas Fox said that reference having been made in the Paper to the River Ribble, in the Estuary of which stream Mr. Brunlees and he had for some years been together engaged upon the reclamation of land for a private owner, some facts relating thereto might be interesting. For most of the observations upon which these notes were based, the Engineers were indebted to Mr. Thomas Ogilvy, of Rufford. An intake of 700 acres of land had been made in 1862. Since the completion of this work, the accretion on that part of the foreshore had been much more rapid, owing probably to two causes. The sea having been excluded from the enclosed portion, the area of 2,000 acres, or thereabouts, between the embankment and the low-water channel, was relieved from the action of the receding tide, which Mr. Fox.

[1] "At Havre, on the French coast, the high-water remains stationary for one hour, with a rise and fall of 3 or 4 inches for another hour, and only rises and falls 13 inches for the space of three hours; this long period of nearly slack water is very valuable to the traffic of the port, and allows from fifteen to sixteen vessels to enter or leave the docks on the same tide."—"Tide Tables for the British and Irish Ports for the year 1886." Computed by Staff-Captain H. R. Harris, R.N., Hydrographic Department, Admiralty, page 111.

Mr. Fox. previously flowed over the 700 acres, so that the solid matters carried up by the flood-tide, and deposited at high-water, were not to the same extent removed by the ebb. During the last thirty years, the volume of sewage brought down by the river from Preston, and other towns, had greatly increased. The sand borne in by the flood-tide, rushing up the low-water channel, and over the lower sands, became mixed with this sewage, and thus was rendered more cohesive and more difficult of removal by the ebb, the result being, that the sands were raised more quickly to the samphire and grass-bearing levels. This sewage also added very much to the fertility of the sands, and, when they reached the grass-bearing level, the grass grew more rapidly and in greater profusion, and so caught more of the *débris*, which covered it at every tide. The layers of vegetable matter to be decomposed were consequently thicker, raising the level of the foreshore, and increasing the richness of the deposit. It had been observed that, in the Ribble Estuary, samphire grew on sands which were beyond the reach of all tides of less than 14 feet 6 inches above Old Dock Sill at Liverpool, or about 10 feet 6 inches above Ordnance Datum, and that grass would grow when beyond the reach of all tides less than 15 feet above Old Dock Sill, or 11 feet above Ordnance Datum. High-water level at the point in question varied from 6 feet to 17 feet above Ordnance Datum. During the present year one hundred and ninety-seven tides would not rise to 10 feet 6 inches above Ordnance Datum, and two hundred and forty-two tides would not rise to 11 feet above that level. Thus samphire would grow where 27 per cent. of the tides of the year did not cover the sands, and grass would grow where 33 per cent. of the tides did not reach it. When once the grass had started, the rise in the level went on rapidly till it reached about 12 feet 6 inches above Ordnance Datum; after that progress was much slower, as so few tides exceeded that level. When the embankment of 1862–63, which reached from the river Douglas to the boundary between Hesketh and North Meols, was finished, there were about 150 acres of green marsh left outside of it, near the river Douglas. All the rest was bare sands. In 1880, when the new enclosure was commenced, more than 1,200 acres were covered with grass. The second enclosure had reclaimed 1,077 acres, the embankment being about $3\frac{3}{4}$ miles in length, having its top 24 feet 6 inches above Ordnance Datum, or about 12 feet above the level of the sand, and 7 feet 6 inches above the highest tide (Fig. 5). This embankment was formed of the sand, protected by sodding, the sods being cut from the marsh outside the bank, and had a width at the top of

3 feet, with slopes of 5 to 1 outside, except the top 4 feet which had a slope of 3 to 1, and 2½ to 1 inside. It had withstood with perfect safety the very high tides and severe storms to which it had been exposed. Mr. Fox would, however, prefer in future a width at the top of from 4 to 5 feet. The total cost of this reclamation had been about £15,000, or £14 per acre. About 800 acres had been already let at £3 10*s.* per acre, and the remaining 277 acres were being let at £3 per acre. The crops of oats during 1885, the first year of cultivation, had been abundant. A large tract of sands lying below this reclamation was now ripe Mr. Fox.

FIG. 5.




RECLAMATION EMBANKMENT, RIVER RIBBLE.

Scale 24 feet = 1 inch.

for enclosure, and the works would probably be commenced this year. The low-water channel of the Ribble had been much improved by the training-walls (rising a few feet above low-water) so far as they extended. Previous to their construction, and when they had been allowed to fall out of repair, the channels of the Ribble, and of its tributary the Douglas, were constantly shifting, as in the Dee and the Humber. The training-walls had, however, undoubtedly hastened the accretion on the foreshore, and the reduction of the tidal-area; and it was evident that if the channel was to be satisfactorily maintained, they must ultimately be extended sea-ward beyond the limits at present authorized.

Sir ROBERT RAWLINSON, C.B., wished briefly to compliment the Author on the clear way in which he had brought the subject of the Paper before the Meeting. There was, however, one point connected with works of that description which ought never to be forgotten, namely, that French engineers were appointed by the Government, and that the works were executed by the Government out of Government funds. They were therefore not necessarily in their character commercial undertakings, there being very probably little consideration as to whether an adequate dividend would be returned for the money expended or not. In England the opposite method prevailed. Englishmen chose to do their works in their own way, Government doing very little for them except sometimes making it both difficult and costly to Sir Robert Rawlinson.

Sir Robert Rawlinson.

get a Bill for any useful public work passed through the two Houses of Parliament. Then after this Bill had passed, the English engineer was left, with his Company, to his own devices. Works of the character described in the Paper had been carried out in England, not however upon such a scale as the improvements of the Seine and its tributaries, but exclusively for commercial purposes, and those purposes had been answered. The question for consideration in future, remembering that time was one of the great elements in modern civilization, would be, whether works like those completed on the Seine would be worth the cost involved in their execution and maintenance. He did not know any English work that could be compared with the works on the Seine, except, perhaps, the Caledonian Canal, which was a Government work, carried out by the Founder of The Institution of Civil Engineers, and who was for the time being acting as a Government officer, and although this fine work had been carried out under favourable circumstances, like a good deal of the French work, it did not pay. The future of canals and of river-improvements would, in his opinion, be a very limited one, chiefly because the cost would be too great for the results proposed to be obtained. The information relating to the hydrology of the Seine was very interesting. A contrast had been drawn between the Seine and the Thames. Having been chairman of the Royal Commission for inquiring into the condition of the Thames, he necessarily knew something of the subject, as it had been his duty to examine the river minutely from its rise in springs to its estuary. It had been navigated rudely "time out of mind"; but the first Acts passed to bring it into a more modern form of navigation were in the reign of George II. The works under these Acts were carried out by Commissioners, whose powers passed into abeyance when the new Conservancy Board was appointed. This Conservancy Board had been blamed for letting the upper part of the Thames go to ruin, and for not having spent sufficient funds upon it. When, however, the care of the Thames passed into the hands of the present conservators, their income was very small; and their present income they owed in some measure to his exertions. When the Act was passed, he proposed in the Committee that the Water Companies should pay a rent for the water abstracted to maintain the Thames and to improve it, and, as it was the great source of water-supply to the Metropolis, to cleanse it; and the better to enforce his meaning, he also introduced the phrase to "scavenge" it, for at that time it was most disgracefully filthy, carcases of animals floating about on it, and weeds multiplying until they impeded

the flow and corrupted the water. At that time the Water Companies were taking daily many millions of gallons of water from the Thames for commercial purposes, but paid little for it. One of them, he believed, paid £1,000 a year, and some did not pay anything. He proposed that each Company should pay at a rate of 6*d.* per million gallons of water taken by it; but certain Members of Parliament, with a view to popularity, opposed that mode of taxing the Companies. He, however, told the Companies then, as he should tell them again, that for their own security it was advisable to get statutory rights to take the water to pay for those rights, and then to scavenge and adopt and carry out works and means to protect the river from abuse and impurities. One or two Bills had since been passed to increase the contributions, and the Conservators now had, he had just learned, an income of £17,000 a year. The reason why the Thames decayed under the superseded Commissioners was that they got into debt. When they were put on one side by the Bill which arose out of the report of the Rivers Pollution Commissioners, the traffic did not pay, and the opening of railways rendered improvement for commercial purposes hopeless, and as they were £80,000 in debt, they did not see their way to safely increase that debt, and so their powers lapsed, and every farthing had been lost. Sir Robert Rawlinson.

The statement as to rainfall was very interesting, and he wished to make a few remarks on that subject, and as to the volume of water flowing off the ground. The Author had stated that there was a greater rainfall in summer than in winter, and that a less volume of water flowed from the ground in summer. That was easily accounted for. In summer, though there was a larger volume of water, if the rain did not come down for several weeks continuously, although the season might be a wet one, very little water would be given to the springs and watercourses. In dry summer weather 2½ inches of rain might fall within seven days, and not a drop would show itself either in spring or stream. Unless rain fell continuously week after week in summer, very little water was added to the streams. As to permeability, if it was a question of excessive floods—those that did the greatest mischief —it mattered very little whether there was a large area which was permeable, or a large area which was impermeable, for the one under continuous heavy rain became exactly the same as the other, as when the permeable stratification had been filled, as it were, up to the brim, the water falling on it subsequently ran off as from a slated roof, and when there were long continuous rains month after month, the proportion flowing off the surface

Sir Robert Rawlinson.

throughout the year might not be more than two-thirds of the rain which had fallen. The Author had stated that the average rainfall in the Seine basin was 27·24 inches, and he had given both the dry-weather and wet-weather flow. Sir Robert Rawlinson had been able to obtain a rough and ready mode of arriving at a minimum and maximum of a district, if he could only get a series of rain-gauge tables sufficiently long. Taking an average and dividing it by three, then if one-third was deducted, it would give the approximate dry-weather flow, and if one-third was added, it would give the approximate wet-weather flow; the ultimate result being that a dry season was to a wet season about as 1 to 2.

In the English climate, the order of seasons was different from that popularly imagined; spring was the driest season, and April was the driest month; autumn was the wettest season, and October and November were the wettest months. A flood would discharge from a given surface five hundred times the minimum volume of water in a dry season, and in some excessive cases, a thousand times. Those were facts that all young engineers having to deal with water should thoroughly comprehend, as it was that excessive variation in the volume of water flowing down natural channels which made river-improvement so difficult and costly. The irregular contouring, due to the rolling, digging, and disturbing motion of a volume of water in flood coming down with considerable rapidity was evident. In a canal there were level reaches from lock to lock, and an even depth, and an even bottom could be maintained, only requiring occasional dredging to remove side-bank subsidence, uprising, and silting; but in a river like the Seine, the Thames, or any other where there were great floods, the bed was constantly exposed to an incessant disorganization, that was, the bed of the channel between lock and lock. Reference had been made to the possibility of taking sea-going ships to Paris. That dream would never be realized. The Seine was a much more important river than the Thames in regard to its hydrographical area, which was five times as great, and its length also was considerably greater; but the Thames was one hundred times more valuable for commerce. It was true that Paris stood upon the Seine as London stood upon the Thames; but from London Bridge to the sea there was a magnificent navigable channel up which the greatest ships that traversed the ocean could go, and there were docks unequalled in the world, except at Liverpool, to accommodate the shipping, so that for commercial purposes the Thames, in comparison with the Seine, had an enormous advantage; and if engineers did not learn something from these facts,

they were wasting their time. He did not say that they might not learn much from reading the Paper and looking at the diagrams; but they would never learn all that was required unless they thought out for themselves the problems involved. When young engineers were called upon to construct works of that character, they should take fairly into account the fact that there were certain operations of nature which ought to be thoroughly mastered, otherwise the works would rapidly come to ruin. There were regions which Englishmen were colonizing, where the rivers rose 70 feet vertically in flood, and there were others where, for a series of years, the rivers were dry pools, and in floods rose 120 feet vertically. The improvement of navigation in such rivers would, he thought, be a very difficult problem. But there were other regions where there were great lakes that might be connected, great areas of country that might be opened out. There was, therefore, in the future plenty of work for ambitious young men. The Gota canal connected Göttenburg with Stockholm, between which places there were two magnificent lakes, the Wener and the Wettern, and useful as the canal had been, and now was, it had been found that in the present day, when time was money, it was necessary that it should be supplemented by a railway. He was not quite sure that some day it might not also be found necessary to supplement the Caledonian canal by a railway running parallel with it through the valley. As to the question of rainfall and evaporation, it was, he believed, Dalton who said that, taking the whole circumference and area of the globe, as far as it was known, evaporation might amount to 36 inches per annum. If that were so, precipitation must be an equal volume, the one regulating the other. The great source of evaporation was the salt ocean, and the great power causing evaporation was the sun. If the heat of the sun was regular year by year, which he doubted, there would be year by year the same amount of evaporation and the same volume of rainfall in precipitation. Evaporation and precipitation were unceasing over the entire area of the globe, from the tropics to the poles. Storms and rainfall were, however, unequal in time and partial in areas. Very little rain fell over flat deserts; excessive rain prevailed along the sides of mountain ranges. Seasons of extreme drought alternated over limited areas with seasons of excessive wet, with an unceasing evaporation. If, however, in the earth's revolution through cosmical space, vapours from the atmosphere were abstracted and lost in space, however minute the annual volume might be, yet the time would come when the ocean would be dried up, the atmosphere vanish, and the earth

Sir Robert Rawlinson.

Sir Robert Rawlinson.

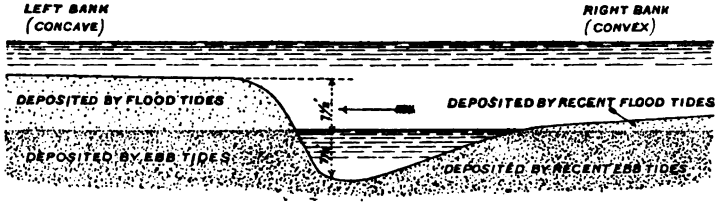
become rugged and crumpled-looking like the moon. Then would be the eve of the final catastrophe foretold by Hebrew prophets, and indicated by Shakespeare in the "Tempest," where Prospero explained to his astonished and wondering auditors the prophetic lines —

> "The cloud-capp'd towers, the gorgeous palaces,
> The solemn temples, the great globe itself—
> Yea, all which it inherit—shall dissolve,
> And, like this insubstantial pageant, faded,
> Leave not a rack behind."

Mr. Deacon.

Mr. G. F. DEACON said the Author had stated that "the Seine works demonstrate that accretion is the result of training-walls, whether high or low, in a shifting sandy estuary." That passage had been the subject of adverse criticism, and as he felt satisfied of its truth he wished to consider it in the abstract, though for the sake of example, and to fix the ideas, it would be necessary to

FIG. 6.




employ figures relating to a particular case. There was one law which he thought held good for all alluvial or diluvial plains, from the first flat-land traversed by the mountain stream, to the sheltered sands of some great estuary, namely, that the concave bank of the channel was always higher than the convex bank. If levels were taken along the two banks, that would be found to be absolutely correct, assuming always that the alluvium and the channel were left to themselves. The reason for this was obvious. As a specific example he had prepared a section, Fig. 6, representing the mean condition of the low-water channel in the 10 square miles of the Upper Estuary of the Mersey, included between a straight line drawn from Ellesmere Dock to Speke Hall, and a straight line drawn from Stanlaw Point to Dungeon Point. That section was typical of all rivers in alluvium, though in other cases the dimensions would not be the same. In the particular instance cited the circumstances were these:—There were, on the average, rather more than 4½ ozs. of silt per cubic yard of water brought from seaward by every tide. Supposing

the whole of that silt were deposited in the Inner Estuary, and not again removed, the rate of accretion at any point in the Inner Estuary would be about 1 foot per annum if the mean rise of the tide were 10 feet above the place of deposit, and much in the same proportion for other mean depths of water. On reference to the typical section, it would be seen that the left and steeper bank of the channel was 7½ feet higher than the right bank, which itself was 7½ feet higher than the bottom of the channel. The left bank was the concave bank; the right bank was the convex bank. By erosion of the left or concave bank, the channel travelled laterally towards the left at the mean rate of 450 yards per annum, and it passed over an area about equal to the area of the 10 square miles in question once in ten years. In moving laterally to the left, the water carried away the whole of the concave bank, 15 feet in height, the lower part of which was marked "deposited by ebb tides," and the upper part of which was marked "deposited by flood tides." Where did it take the material of that bank to? Manifestly it took just half of it away from that part of the river altogether and carried it towards the sea. The other half it deposited on the right bank, thus maintaining the width of the channel constant. The water in a river bend acquired, as had been well pointed out by Professor James Thomson, a helical motion, due to the centrifugal force being greater, owing to greater velocity, near the free surface than near the bottom of the stream. The resultant motion of the upper water was therefore down the channel and across to the concave bank, and that of the lower water down the channel and across to the convex bank. Mr. Deacon would add that by this motion the destination of the eroded material was determined, the finer particles being carried by the upper and middle water towards the sea, and the coarser particles being washed across by the lower water and deposited on the convex bank marked "deposited by recent ebb tides," to the height of the contained stream. Accordingly it was found, and this again was typical of all rivers in alluvium, that for the first 7½ feet above the bottom of the channel the material of the banks was coarser than in the upper 7½ feet on the higher side. As the low bank was thus built by the channel on the concave side, the tides overflowing that bank began to form upon it another bed marked "deposited by recent flood-tides," and this deposit being brought up chiefly as suspended matter from seaward, was of finer material than the channel-built bed below. On the concave side this tide-built bed had grown to a height of 7½ feet above the convex bank before the channel cut it down again. In

Mr. Deacon.

Mr. Deacon. the case of alluvium proper the corresponding effect was produced by land floods. He thought it must be obvious to everyone that the slower the lateral motion of the channel the higher would the flood-built bank become, and the higher would be the mean level of all the sands; and if the channel ceased to travel laterally, it was equally obvious that there was no limit except height of tide to height of accretion. The tide at present rose above the concave bank of that particular channel to a mean height of 13 feet, so that if all the silt were deposited there would be an accretion of 8·4 feet. There actually was an accretion of 7·5 feet, showing how large a proportion of tide-borne silt was deposited and only returned to the sea through the agency of the low-water channel. He had previously stated that if all the silt brought from seaward by the tides were deposited in the Inner Estuary and not removed, the rate of accretion would be 1 foot per annum for each average tidal-depth of 10 feet. Hence, having regard to the diminishing depth of water as the deposit increased, the corresponding depth of accretion in ten years would be 6·5 feet, and in the case in point, where the initial mean tidal-depth was 13 feet the accretion in ten years would be 8·4 feet.

Mr. Leader Williams had stated that "as there were sand-banks in the Mersey, particularly one at Eastham, through which the low-water channel had not gone for many years, and that bank had not increased above its ordinary level, it was evident that the natural powers there were sufficient to keep it down to that level." Mr. Deacon, however, could only find one bank of any importance, across which, during ten years, the channel had not travelled, and that was near the middle of the Estuary between Stanlaw Point and Oglet Point. In the decade from 1871 to 1881 a large portion of that bank was apparently not affected by the channel. The mean accretion during that period was 4½ feet. The mean rise of the tide above the height of the bank at the beginning of the period was 9 feet, so that, in this case, if all the tide-borne silt were deposited, there would be an accretion of 5·7 feet, while there actually was in that decade an accretion of 4·5 feet. It had been stated that because the Cheshire side of the Mersey was 5 per cent. longer than the Lancashire side, therefore the ebbing tide flowed down the Lancashire side; but the fact was that the ebbing tide did not do so. It took for its maximum velocity a path which was on an average 30 per cent. longer than the Lancashire side. The ebbing tide might have been expected to flow down the concave Cheshire side, towards which it was projected by the direction of

the Estuary immediately below Runcorn Gap. The reason why it failed to do so was because on that side the River Weaver and several smaller streams flowed into the Estuary, and they tended to form deltas and lateral banks, which, together with the momentum of the tributary waters, pushed the Mersey channel away: and thus although, *cæteris paribus*, its natural position was near the concave Cheshire shore, it was in fact ever changing, and on the average flowed nearer to the Lancashire than to the Cheshire shore. These conflicting influences were, he believed, the salvation of Liverpool; for if from any cause the Cheshire affluents ceased in this respect to perform their present functions, the low-water channel would undoubtedly tend towards the concave Cheshire shore, and would become less unstable, and nearly in proportion to its instability would be the resultant capacity of the tidal-basin, upon which the sectional-area of the bar-channel was dependent. He said sectional-area advisedly, in preference to depth, as much misapprehension had arisen from comparisons of depth alone. It was true, however, that the larger the channel, the deeper on the average it would generally be. Mr. Deacon.

Mr. J. W. BARRY considered the Paper valuable in two ways, in one way as dealing specially with questions of great interest in connection with the description of the Seine, in regard to inland navigation, and in the other in considering certain general principles in the treatment of an estuary, and applying them to the special instance of the Seine. He would not refer to the details of the Upper Seine, but would allude briefly to those general principles which interested engineers in their application to an estuary. If the velocity of water was diminished, the matter in suspension, which corresponded to the velocity, would be deposited, and it did not much matter, when these principles were being considered, how the velocity was diminished. Again, if the velocity was increased in one part of the cross-section of a river, the velocity in the other parts of the cross-section would be diminished. Therefore, if training-walls were put in a river, whether parallel to the course of the river or at right-angles thereto, the purpose and certain result of which was increase of velocity locally, deposition might be expected. In the Mississippi, deposition had been intentionally encouraged by all kinds of ingenious devices by Mr. J. B. Eads, M. Inst. C.E., who had given instances in which the mere placing of nets or light hurdles in the river had checked the velocity of the stream, and caused considerable banks to be formed, which by narrowing the river had increased the navigable channel in depth, and tended to those great improve- Mr. Barry.

Mr. Barry. ments with which his name was so honourably connected. If, on the other hand, a deep-water channel in the river was dredged, and the hydraulic mean depth thereby increased at one particular portion of the cross-section of the river, the velocity of the water would be increased in that portion, the velocity at other parts of the cross-section of the river would be diminished, and deposition would take place on each side of the channel. He therefore could not agree with the principle that had been laid down by some of the speakers, that unless training-walls were raised to the level of high-water or half-tide, deposition would not take place. He believed that training-walls, of whatever height they might be, tended to make a deep-water channel, and to increase the velocity at one portion of the cross-section of the river, and that they would infallibly tend to deposition at adjoining portions. Thus, it was not possible to lay down any general mode of treatment which was applicable to all rivers. Sometimes accretion was not of much consequence, and a deep channel was of primary importance. In these cases it would be possible boldly to adopt training-walls or jetties, or dredging, or any other mode of increasing the hydraulic mean depth of the channel. But in other instances accretion was of vital consequence; it might tend to the destruction of a port, which was dependent upon the flux and reflux of the tide to keep the bar open. Again, in some cases the increased quantity of tidal-water due to making or deepening a channel might, for scouring purposes, counterbalance the quantity of water excluded by deposition, while in other cases, and especially when a great part of the deepening took place below the level of low-water, the increased quantity of water in the channel would not be worth consideration. With regard to the Manchester Ship-Canal scheme, he thought the Author was perfectly justified in his statement, that if the principles he had laid down, and which he might observe were well known, had been sufficiently apprehended at the outset of the project, the two abortive attempts in Parliament to which he had referred would not have been made. He thought that every one had learned a great deal from those attempts, and whatever some engineers might think about it, Parliament, at any rate, was thoroughly convinced that the training-walls first proposed could not be put in the upper portion of the Mersey without the greatest risk of deposition, and the consequent exclusion of the tidal-water, which was admittedly necessary for the maintenance of the channel over the Liverpool bar. Engineers were able to say that training-walls would be very useful in developing a channel, but that a new channel could not be de-

veloped without decreasing the velocity in other portions of the cross-section of a river; and in recommending such works as training-walls, or cross-jetties, or any other mode of developing a channel, they should be prepared for deposition, which might or might not in each particular case be of consequence. The importance of deposition depended first of all upon the quantity of silt or sand held in suspension, and then upon the secondary results arising from deposition in the exclusion of tidal-water. Mr. Barry.

Mr. VERNON-HARCOURT, in reply, said with reference to the additional information concerning the different classes of strata desired by Mr. Baldwin Latham, he believed this was somewhat indicated by comparing the two plans of the Seine Basin (Plate 1, Figs. 1 and 2), and noting, at the same time, the information given in the Table accompanying them, of the geological nature of the several districts. Further information, however, could be found in a coloured geological map of the basin, in Mr. Belgrand's book on the Seine,[1] which was also given in Mr. Préaudeau's manual;[2] but this map would have been too costly to add to the numerous illustrations accompanying the Paper. He had only referred to the new Seine weirs as possibly applicable to Indian rivers (p. 45), and not to the other works on the Seine, as General Rundall appeared to suppose. General Rundall had pointed out that the form of the basin might exercise an important influence on the floods of a river; and to this interesting consideration he would add, that the positions of the confluence of the tributaries, and the situation of the higher parts of a basin in relation to the sea and the prevailing winds, must also have a considerable effect on the floods of the main river. Mr. Taunton had described the defective condition of the Thames between Oxford and Lechlade, which he could fully corroborate, as he was intimately acquainted with that portion of the river, having taken numerous cross-sections along it, and traversed it several times for the Upper Thames Valley Drainage Commissioners. From information which he had received when consulted last autumn about the river near Oxford, he gathered that the Thames Conservators had been obliged to capitalize a large portion of their income in order to raise adequate funds for rebuilding numerous weirs, and also some locks, being aided in the works on the upper river by the Commissioners. Accordingly, the Conservators would in future have no funds available for carrying out improvements beyond the Mr. Vernon-Harcourt.

[1] La Seine, Études Hydrologiques, p. 27; in Atlas, pl. 1.
[2] Manuel Hydrologique du Bassin de la Seine, pl. 1.

Mr. Vernon-Harcourt.

works now in progress; and the Commissioners, who had certain powers of rating for drainage improvements, were not able to obtain sufficient funds to carry out all the works they deemed expedient. He feared, therefore, that the navigable condition of the Upper Thames could not be materially improved unless the Government took in hand the inland navigation of the country, a system adopted in France, India, the United States, and other countries. Sir R. Rawlinson's view that such works were generally unremunerative, might be true as regarded private enterprise; but it did not follow that the State would not gain by these undertakings. For the State derived an indirect benefit from the increased prosperity of the nation, and from improved facilities for trade, by the augmentation of taxable property; and this was considered in France, and probably in the United States also, to provide an ample return on the expenditure.

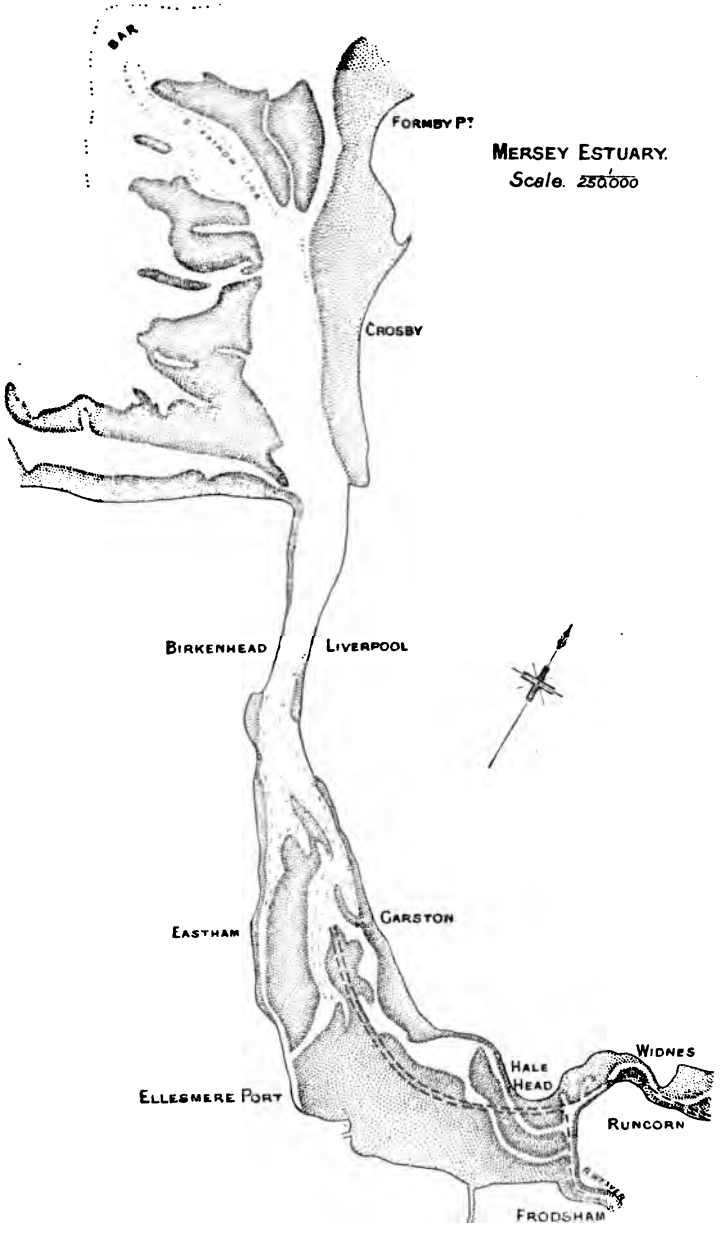
He could not agree with Mr. Leader Williams in considering solid weirs the best for English rivers, though he thought that large weirs of the type of Poses and Port-Mort were too costly to be adopted in England. He was of opinion that improved forms of draw-door weirs, of which Mr. Stoney's design was an instance, Mr. Wiswall's tilting-weir, and the smaller and simpler forms of French movable weirs, might be adopted with great advantage on English rivers. An automatic system for weirs, which was advocated by Mr. Giles, had been tried at the earlier shutter-weirs on the Seine; but the working had proved uncertain; and, except for the butterfly-valves in the more recent shutters, the system had been relinquished in favour of a regulation of the flow directed by the weir-keeper, who could be warned, in his cottage, by an automatic bell, of a rise in the river necessitating his attendance. He was surprised that Mr. Shoolbred, who claimed to have some acquaintance with the Seine, should have fallen into the error of supposing that the footbridge of the needle-weirs was a permanent obstruction in the river; whereas he might have ascertained from the Paper on "Fixed and Movable Weirs," from Plate 3, Fig. 5 of the present Paper, and from the photographs exhibited of Port Villez weir, that the frames were lowered into a recess in the apron in flood time. It would have been fairer also to French engineers, in comparing their weirs with the tilting-weir, to have selected the shutter-weir, or the more recent forms of frame-weirs, as examples, rather than the needle-weir introduced half a century ago. The obstruction in the tilting-weir, when opened, (described as slight) constituted one-fifth of the whole waterway, for the frames and gates remained in mid-stream;

but he considered this the only disadvantage in this form of weir, which in other respects was very satisfactory. Mr Vernon-Harcourt.

Several speakers had discussed at some length his allusion to the proposed training-works in the Mersey. A consideration of the results of the Seine training-works led him to express an opinion adverse to the improvement of the Mersey Estuary by training-walls, early in 1882, in his book on "Rivers and Canals," and in his Paper on "Harbours and Estuaries on Sandy Coasts," before the first Manchester Ship-Canal scheme had been brought forward; and he was confirmed in this opinion by an inspection of the Ribble Estuary for the Southport Corporation in 1883. A description of the objections to training-walls in the Mersey did not enter into the scope of a Paper on the Seine; and his views were well-known, having been given in evidence before five Committees on the Manchester Ship-Canal bills. As, however, considerable prominence had been given to the question in the discussion, he had made a plan of the Mersey, showing the estuary-scheme for the canal of 1884. (Fig. 7, p. 102.) He had never suggested that there was any similarity between the Seine and the Mersey estuaries, as Mr. Shelford and Mr. Leader Williams appeared to imagine. A comparison of Plate 4, Fig. 1, and Fig. 7 sufficed to show how unlike they were in form. They resembled each other, however, in having large accumulations of sand, a considerable range of tide, and a shifting channel; and there was every reason for supposing that the results of training-walls would be similar in both estuaries. It had been suggested that the accretions in the Estuary of the Seine were the result of high training-walls; but low training-walls were adopted below Tancarville and La Roque, and still accretions took place behind these low walls, and even extended 8½ miles beyond their extremities. Liverpool Bay was a natural receptacle for wave-driven sand; and the reclamations which had been accomplished by the training-banks in the Estuary of the Dee to the south, and the accretion which had resulted from the low training-walls in the Estuary of the Ribble to the north, showed how inevitably accretion must follow training works along that coast. Both Mr. Shelford and Mr. Leader Williams stated that the inner Mersey Estuary was a tidal reservoir, and they pointed out that the bar at the mouth of the Mersey rendered it different to the Seine. He fully endorsed these opinions, and considered therefore that training-works, which might be comparatively harmless to the outlet of the Seine, would be most injurious to the outlet of the Mersey.

Mr. Vernon-Harcourt.

FIG. 7.



Mr. Vernon-Harcourt.

It was precisely because he realized the important differences between the two estuaries, that he advocated the extension of the training-walls in the Seine, and opposed their introduction in the Mersey. Training-walls produced two effects, namely, the improvement of the channel between them by the concentration of the flow in one fixed course, and the accretion of land behind them owing to the diversion of the scouring influences from the rest of the estuary into the fixed channel; the first effect was a manifest gain, and was fully recognized by engineers; whilst the second might or might not be injurious, according to the form of the estuary and the position of ports or towns on the coast, and was liable to be overlooked. He was fully alive to the advantages of training-walls for affording access to inland ports, and had declined to oppose the extension of the training-walls on the Dee, as he believed that they might be prolonged in that estuary for the benefit of Connah's Quay and Chester, without injuring other places by the inevitable accompanying accretion. The maintenance, however, of the Upper Estuary of the Mersey, as a tidal reservoir, had been acknowledged by the engineers on both sides in the Manchester Ship-Canal inquiries, as essential to the preservation of the channel over the bar; so that the main controversy was limited to the question whether accretion would, or would not have resulted from the proposed low training-walls. Mr. Lavoinne, a zealous advocate of training-walls, had stated, in conversation with him in 1883, that he fully agreed with his opinion that accretion must follow from the proposed training-works in the Mersey. Mr. Thomas Stevenson, M. Inst. C.E., to whose opinions Mr. Williams had alluded, was reluctant at first to admit that training-walls, which he had employed with success in several estuaries, could have sometimes a deleterious effect; but after careful consideration, he fully acknowledged the correctness of Mr. Vernon-Harcourt's views about the Mersey, and gave his conclusions in his Presidential Address to the Royal Society of Edinburgh, on the 2nd of February, 1885,[1] in which he stated, speaking on the principal causes of silting in estuaries, that, if the canal estuary project had been authorized, it might "have ended in something very like a national calamity, namely, the silting up of the sea-approaches to Liverpool." Moreover, in his concluding remarks, speaking of the reduction of tidal capacity which would have been effected by the works, he said, "not one-twentieth, which Mr. Walker feared to authorize at the Tay—not

[1] Proceedings of the Royal Society of Edinburgh, vol. xiii. pp. 82, 91.

Mr. Vernon-Harcourt.

one-tenth, as has actually taken place at the Lune—but one-half of the whole scouring-power would be excluded from the Estuary of the Mersey." Mr. Deacon and Mr. Barry had well described the natural causes which must produce accretion if a channel was fixed by training-walls in an estuary like the Mersey. Mr. Leader Williams and Mr. Giles adhered to their former opinion that low training-walls would only improve the channel between them without influencing the rest of the estuary, which he believed was contrary to the laws of nature, and was not in accordance with his experience of other estuaries. Mr. Shelford and Mr. Williams stated that the proposed Mersey training-walls reached deep water; but it was evident from Fig. 7 that this was not correct, for sandbanks extended in front of them, and the bar was beyond. Had the training-works been carried out, the accretion would have gradually crept down beyond them, closing up the channel to Garston Docks, and they would have needed extension to the narrows; the great reduction in tidal capacity would have shoaled the bar-channel, and works would have eventually been necessary in the outer estuary to regain the present depth. Accordingly, the authorized canal scheme, by not interfering with the estuary, was far better for Manchester, as it did not imperil the bar-channel; and, moreover, it did not endanger the approaches to Garston and Ellesmere Port. He was surprised that Mr. Pember considered the narrows the critical portion of the Mersey Estuary. He had never suggested that the narrows would be silted up by loss of tidal capacity above, but that the bar-channel would be affected, which was the vital point for Liverpool. Mr. Pember would see in Appendix III. that the main channel at the entrance to the Seine had decreased 23 feet in depth between 1875 and 1880. This reduction had indeed occurred in sufficiently deep water not to affect the access for vessels; but what would be the effect of any such diminution in depth in the bar-channel of the Mersey? Mr. Pember considered that it had been proved that the depth over the Mersey bar bore no relation to the capacity of the Upper Estuary. The influence, however, of the tidal capacity must be measured by the total sectional-area of the outlet, and not by the maximum depth at any one point. No uncertainty, he believed, existed amongst engineers as to the effect of tidal scour on the Mersey bar-channel. The channel owed its existence to the tidal-current, and would be obliterated if the tidal action ceased. The value of tidal scour in maintaining an entrance channel had been amply proved in his Paper on "Harbours and Estuaries on Sandy

Coasts"[1]; and the deterioration of the outlet was shown to result invariably from a reduction of tidal capacity above. The only other influence at work in maintaining the outlet of a tidal-river, against the heaping-up action of winds and waves along the coast, was the fresh-water discharge. The average fresh-water discharge of the Seine was about twenty-eight times that of the Mersey, whereas its tidal capacity was less, which showed how far more the maintenance of the Mersey outlet was dependent upon tidal scour than the Seine. Mr. Giles and Mr. Fox agreed with him as to the necessity of a future extension of the Ribble training-walls, beyond their present authorized limits, to maintain a navigable channel. Mr. Fox had also confirmed his statement that accretion and reclamation had resulted from the existing low training-walls. The prospect these conclusions held out might be satisfactory to the riparian landowners, who would be able to make further reclamations; it would hardly be equally so to the Preston Corporation, who, whilst greatly reducing the tidal capacity of the Ribble Estuary, would be obliged to undertake considerable extensions of the training-walls; and it would be very serious for Southport, a favourite seaside resort, which would be gradually deserted by the receding sea, and thus lose the very object of its existence. Mr. Giles had stated that the Bog Hole, at the head of Southport pier (Fig. 1), had increased of late years in depth. He thought that this local action was due to the extension of the pier-head. The channel, however, had decreased in length, and the hollows to the north of it were shoaling up. At present the Bog Hole was maintained by the tidal current filling and emptying the extensive estuary to the north-east; but when the training-walls were extended, the tidal flow would be greatly reduced by the accretions and reclamations, and the channel would silt up. Mr. Vernon-Harcourt.

Some objections had been raised by Mr. Wells Owen to Appendix III, in which he had given a translation of the summing up of Mr. Germain's report, with a short explanatory paragraph at the end, for which alone he was responsible. If Mr. Owen had carefully considered Mr. Germain's figures as they stood, he would have seen that, as was stated in the Author's paragraph, Mr. Germain gave in each line of his Table, not the accretion or erosion of each section separately, but the total accretion or erosion from the Rille lights, at the ends of the training-walls, up to the meridian named in the central column. Accordingly, the last line stated that the total accretion (after deducting the erosion in some of

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 1.

Mr. Vernon-Harcourt.

the sections) between the Rille lights and St. Christophe, the extreme limits east and west of Mr. Germain's survey amounted to 40,244,100 cubic yards, a fairly simple and comprehensible statement. He had considered that it would have been clearer to have given the actual accretion or erosion in each division separately, ending up merely with their sum; but this could be obtained from the figures given, which he had not felt at liberty to modify, and he had pointed out in which divisions accretion or erosion had actually occurred. Mr. Owen was misled, by his erroneous reading of the statistics, into supposing that erosion had occurred in five successive sections between 1875 and 1880; it had only occurred, as stated in Appendix III, in the second, third, and fourth divisions, and in the last. The chief erosion had occurred in the second division, amounting to 10,274,000 cubic yards, owing doubtless to a considerable variation in the channel during that period, resulting in a temporary augmentation at that part of the capacity of the estuary without any permanent improvement in the shifting channel, just as Mr. Pember pointed out had occurred in the Upper Estuary of the Mersey. Mr. Owen had concluded that the training-walls had improved and deepened the channel for 8¾ miles below their extremities, whereas a glance at Plate 4, Figs. 1 and 8, would have shown him how changeable the channel was even a short distance beyond the ends of the training-walls, and that, whilst in 1880 there was a continuous channel to the sea at low-water, a bar had formed across the channel in 1883 within 4 miles of the ends of the walls.

Probably the sand scoured out of the bed of the river, directly after the construction of the training-walls, had settled in another part of the Estuary; but Mr. Estignard had made due allowance for this in his calculations of the reduction in capacity, and therefore the figures quoted from his Report gave the excess of the accretion beyond the amount which might be assumed to have come out of the deepened channel. Mr. Abernethy was therefore mistaken in attributing the accretion merely to the deposition of the material scoured from the trained-channel; for this displaced material was not only considerably less in quantity than the accretion measured, but had actually been allowed for in the calculation.

He agreed with Mr. Giles in regretting that the river had been trained in so sinuous a course. Only a small modification, however, would have been possible, owing to the proximity of high land on each side; and probably the very unsatisfactory line between Aizier and Tancarville, where two very sharp bends were

connected by a straight reach, was adopted to save a second training-wall between Aizier and Quillebeuf. Nevertheless, the bend between Quillebeuf and Tancarville should have been made as gentle as possible, for it increased the difficulty of extending the trained channel towards Havre, and checked the influx of the tide. He did not share Mr. Shoolbred's gloomy anticipations of the sacrifice of Havre. It was curious that Mr. Shoolbred, whilst so strongly insisting on the yearly increasing injury of the existing training-walls to Havre, and the danger of interfering with an estuary, should advocate the scheme of Mr. Lavoinne, who considered that benefit had resulted to Havre from the works, and whose proposed southern training-wall interfered much more with the Estuary than his own. It would have been better for Havre if no training-works had been commenced, as then Havre would have been secure from any chance of injury by the great transformations in the Estuary; but Rouen had its claims to consideration, and he believed that it would be possible to complete the works, as he had indicated, without endangering the approach to Havre. Sir James Douglass had stated that the deep water had been trending northwards since 1776; but it was clear from Plate 5, Figs. 1–4, that since 1834 the 5- and 10-metre lines had moved considerably southwards. Sir James Douglass also assumed that the deposit had come down the river; whereas in reality the river was clear, and the deposit came in from the sea, and therefore it was not necessary to narrow the outlet in order to drive the deposit out to sea, as in the case of a sediment-bearing tideless river. Accretion would only occur behind the training-walls, provided the oscillation of the tidal current was unimpeded. Accordingly, he considered that it would be unwise to arrest the silt-bearing tidal-current by a sort of groyne across the Ratier Bank, as it would cause a great advance of the beach in front of Trouville, which, though of little consequence as a port, was a flourishing seaside town, and should not be damaged without urgent necessity. Moreover, the southern wall projected by Mr. Lavoinne, by preventing the free ingress of the southern tidal current, and diverging northwards across the mouth of the river, would produce a conflict of currents at the outlet, leading to deposit of silt. He believed also that the free admission of the southern current would be more valuable in maintaining a central deep than injurious in producing accretion. After the banks became raised behind the extended walls, an equilibrium would eventually be re-established in the Estuary, provided the tidal influx was not unduly restricted. The average depth at the outlet

Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. would doubtless be somewhat reduced, owing to the reduction of tidal-capacity in the estuary; but this would be of less importance than in many other estuaries, on account of the ample depth existing at present.

## Correspondence.

Mr. Caland. Mr. P. CALAND observed that the Seine in so far resembled the Clyde, that on both, the trained lower river ended in an estuary opening into a bay of large superficial extent. The conditions on the Clyde were, however, much more favourable than those on the Seine, as according to the Report of Mr. Deas, of 1873, the last that Mr. Caland had received, the depth of water in the mouth of the lower channel of the Clyde had increased since the erection of the training-works, a result that had not, according to the Author, been attained in the Seine. In a scheme of improvement for the Seine, the interest of both Honfleur and Havre must be considered, which places were on opposite sides of the bay, and close to its mouth. In 1856 Mr. Caland was commissioned by the Netherlands Government to investigate, among other subjects, the condition of the Seine, and his Report, published on the 15th of October, 1856, contained the following paragraph:—"It appears to me that the river-improvement works commenced beyond the Amfard and the Ratier Banks, must be further extended if any useful result is to be obtained." At that time the true nature of the problem did not seem to have been apprehended in France, neither had any general scheme of river-improvement been formulated, and the works were carried out from above downwards (instead of beginning at the sea end and working upwards). The latter course might be explained by the existence of shoals at some distance above the mouth (the Traverse de Villequier and the Flac Bank); but in any case a general scheme for the improvement of the whole river might have been planned. It would then have been apparent that the river was very unduly contracted, and that to provide proper space in the trained-channel it should have been widened at the lower end. That the Estuary of the Seine had become decidedly shallower in late years was not, in his opinion, a matter of surprise. Formerly the sand and mud brought down by the river-flood was deposited in thin layers upon the ground outside the river-bed proper, whence it was carried seawards and dispersed by the waves during periods of storm and high flood-tides; but since the river-bed had been narrowed and deepened, the bulk of the transported material was

deposited beyond the end of the trained-channel as a compact mass in deep water, where it was no longer susceptible of being loosened by the action of the waves. On the Clyde, if Mr. Caland was not mistaken, extensive dredging operations had been carried out between the training-walls, which had not only prevented the formation of shoals seawards, but had increased the scouring-power of the lower river, with the results of increasing the depth of water in the bay as well as in the trained-channels. On the Seine, on the other hand, since the completion of the works, the deepening of the channel had been left to nature, that was, to the river itself. Mr. Caland.

As regarded the Seine, many points seemed to require further explanation. For instance:—Had the velocity of the tidal-current undergone any change since the improvement works had been carried out, and if so, to what extent? How far did the sea-water flow up the river now as compared with former times? What was the reason that the time of high-water and of the turn of the ebb was earlier at Havre than it used to be? That the latter result was due to the deepening of the channel seawards did not appear to be probable; most likely the cause was to be sought in the river itself. Another question of importance was:—Where did the action of the flood cease? In 1856 the tidal-limit was at Poses about thirty-three hours distant above Havre, and it would be matter of the greatest interest to know whether there had not been a change in that limit. Mr. Caland thought there might very well have been. The Author considered the point of principal interest at present to be the improvement of the river between Berville and Havre. As far as he was able to judge without further investigation, the plan proposed by Mr. Lavoinne in 1882 was generally preferable to that of the Author. He would be inclined to carry the left training-line farther out into the river, and to lengthen the harbour of Honfleur, while on the right line he would follow Mr. Lemire's plan and curve, bending it to the eastward of Havre, in order to prevent a possible widening of the stream in front of the latter port, and consequently diminishing the depth at that place.

The width of the mouth of the channel on the Author's plan was far too great, and the funnel-shape necessary in every lower river subject to tidal ebb and flow appeared to him to be better provided for in Mr. Lavoinne's scheme. Whether a widening of the channel above Berville might not result from the works proposed could not be determined without further investigation. True, the difference in width between the proposed mouth and the

Mr. Caland. outer ends of the training-walls was very considerable, but it must be borne in mind that before the river works were executed the like difference existed between the mouth and the river at, for instance, Vieux Port and Aizier, which places, having regard to the entire length of the lower river, were not so very much higher up than Berville.

Mr. Caméré. Mr. CAMÉRÉ wished to acknowledge the value of the Paper, which constituted a complete and interesting monograph of the basin of the Seine. He would limit his remarks to one or two questions treated of in the Paper, and which he hoped to render more clear. The Author, at p. 23, expressed the opinion that, "the variety of types adopted within one river-basin has been due to the desire of the engineers in charge of the different sections to devise some new and improved type, and not to the special adaptability of each type to the localities in which they are situated." As the best means of combating this opinion, Mr. Caméré proposed to give a succinct history of these different types of weir. The earliest artificial improvement of the rivers of the Seine basin, and which went back several centuries, consisted in passes generally constructed in dams of wood and stone, put down for the use of mills and factories. These openings were closed by beams or needles. To these primitive passes, difficult to manœuvre, and occasioning considerable waste of water, succeeded (notably on the Yonne towards the end of the last and the beginning of this century) passes with side-walls and aprons of masonry 26 feet wide, closed by needles bearing at the top against pivoting-bars. Later on the width of the passes established on the River Yonne was increased to 40 feet, and the supporting bar superseded by a cable, stretched or slacked, as needed. The danger and difficulty to the barges in passing through these narrow openings, naturally led the engineers to widen them, and it was this that led Mr. Poirée, in 1834, to increase the width for the Basseville pass to 72 feet, and to support the needles against frames spaced at intervals between the side-walls. Such was the inception of the type of weir which bore the name of the engineer in question, and which, in combination with the employment of sluices, rendered the navigation of the Yonne and of the Lower Seine incomparably superior to its previous state. Notwithstanding its good qualities, due to the fewness of parts and the simplicity of its manœuvring, the Poirée dam manifested the following faults when proposed to be applied for greater heights, either for diminishing the number of reaches, or for increasing the depth of water:—the obligation of applying needles and frames of unmanageable size and weight; the necessity of

combining, with dams of this system, overfalls of considerable extent, and therefore costly: the want of having recourse to incessant manipulation, in order to prevent the service-footway from being submerged, the latter rendered probable by the small height above the pool, manœuvres that might even become impossible on the occurrence of a sudden and brisk rise of the river. The impossibility of keeping the needles sufficiently watertight to maintain the normal depth above the weir, by reason of the flow of the river becoming insignificant. It was to meet these disadvantages that the authorities adopted the Chanoine system for the weirs to be constructed on the Upper Seine in 1860. Nevertheless, experience soon showed that the service of the Chanoine weirs presented serious difficulties, and that they were liable to fall down unexpectedly, thus entailing, by reason of the sudden alteration of depth, grave inconvenience to the navigation. As regarded Mr. Desfontaine's drum-weirs, they did not properly constitute a complete system applicable to navigable passes, but rather allowed of the formation of an overfall of extent sufficient, having regard to the ease of manipulation, to regulate the depth without having recourse to the incessant opening and closing of the deeper weirs, and even to afford valuable assistance in the manœuvring of the latter. In this way drum-weirs had been applied between 1857 and 1867 to the overfalls of the Marne weirs, in which the deep passes were closed by Chanoine shutters. The end kept in view by the authorities in installing on the Upper and Lower Seine, as well as upon its principal affluents, dams of the Poirée or of the Chanoine types, was to give to these rivers a depth of 5 feet 3 inches. In so far as the Lower Seine was concerned, it was soon found that this depth, which was being achieved under the law of the 31st of May, 1846, no longer responded to the growing requirements of the navigation, and in 1861 it was decided to put up new dams of the Poirée type between Paris and Rouen. The inquiries undertaken by Messrs. Belgrand, Krantz, and de Lagrené, having led those engineers to think that increased expenditure necessitated by substituting a depth of 10½ feet for one of 6 feet 6 inches would not be excessive, and the Admiralty, to whom were entrusted the preliminary studies relative to these proposals, having decisively pronounced in favour of the greater depth, the latter was adopted by the law of the 6th of April, 1878. To avoid multiplying beyond reason the number of pools, it was necessary, in order to obtain a depth of 10½ feet, to employ dams of a minimum height of 13 feet. Although the Poirée system had never yet been employed for such heights, it was adopted by the authorities in default of any systems

Mr. Caméré.

Mr. Caméré. of well-ascertained superiority. It was, furthermore, the type of dam prescribed in 1876 for application at Port Villez. Being entrusted with the construction of this weir, he had early come to the conclusion that this enlarged type of Poirée dam went beyond the limits of regular working, not only by reason of the damage that it was to be feared might happen, when being lowered, to frames 18 feet high and weighing nearly 2 tons, but also on account of the difficulty to be anticipated in handling the needles, which were proposed to be nearly 8 inches square.[1] These uncertainties so impressed him that, having to design several other dams for the Seine, he hesitated to adopt a type in which he had so little confidence.[2]

Such were the reasons leading him to seek for a type of weir in which all the shutting parts could, in times of flood, be raised above water-level, and in which the obstruction was compatible with deep water in the pool above, a system having the weir at Poses as a first example, and which was described in the Paper (p. 27). At Poses the fall was not less than 21 feet, and the pool constituted by this dam was 26 miles long. The dam was opened on the 23rd of September, 1885, and had stood the test of the exceptional floods of the Seine in the winter of 1885–86. Its working had left nothing to be desired, and it had proved one thing that deserved to be recorded, namely, that no system of weir with parts lowered on the bed of the river could have been capable of satisfactory working under such conditions as had occurred at Poses. As long as it was only a question of constructing weirs of small fall, the lowering was accomplished before the floods had reached the lower pools, and therefore before the water had brought down much detritus. These conditions did not obtain at Poses, where the pent-up water attained almost to the height of great floods. In this case the quantity of *débris* of all descriptions—grass, branches, snags, whole trees brought down and arrested by the dam—was such as would have rendered almost impossible the working of any weir whose main parts were under water, especially as regarded the frames. Notwithstanding

[1] In the first design it was proposed to work these needles mechanically; as carried out they had been replaced by the Caméré hinged curtains.

[2] Since the opening of the Port Villez dam in 1880 numerous breakages and deformations of the frames had occurred, caused by their bedding on stones and stumps brought down by floods and deposited on the sill. It had further been proved that no moving of the frames could be easily accomplished, even with the weir open, when once the water in the lower pool was 1 metre (3 feet 3 inches) below that in the upper one.

the amount of the obstruction accumulated against the Poses weir before it was raised [1] on the 15th of December, 1885, the opening was effected without difficulty by ordinary means, and without necessitating recourse to the special machinery provided in case of emergency. Mr. Caméré.

The brief history given by him of the Seine weirs would show that the aim had constantly been to keep pace with the demands of the constantly-growing traffic. If engineers still hesitated to pronounce on the rival merits of the Poirée and Chanoine systems as adapted to slight falls, they would nevertheless not doubt that such types were not suited for giving the Lower Seine a depth of 10½ feet, and also they would perhaps come to the conclusion that the Poses weir, in solving this question, had furnished a practical example of a movable dam of great height, and affording every security for working.

The Author's figures, at pp. 26, 28, in his comparison of the cost of the weirs at Poses and Port Villez, needed to be explained, in order that an exact idea might be had of the expense of such structures. At Port Villez, as at Poses, a solid foundation was only found at a great depth, below the beds of gravel and sand forming the river bottom. In order to be beyond the influence of infiltration it was decided to make the Port Villez foundations 24 feet deep; those at Poses were nearly 29 feet below the surface of the sills of the deep passes. These very costly foundations evidently ought not to be considered inherent to the system, and the following figures would give a juster idea of the cost per lineal metre under ordinary conditions, say with foundations 6½ feet deep:—

| — | Port Villez. | | Poses. | |
|---|---|---|---|---|
| | Francs. | | Francs. | |
| Extraordinary foundations . . . . . | | 7,000 | | 7,000 |
| Masonry of the sills, piers, &c., including the metallic fittings of the sill . . . | 4,000 | | 2,500 | |
| Metallic superstructure, and curtains . . | 2,500 | 6,500 | 3,000 | 5,500 |
| | | 13,500 | | 12,500 |

or £163 7*s*. and £151 5*s*. per lineal foot respectively; but inasmuch as the Port Villez weir only retained a pool 15 miles long, whereas that at Poses retained one 26 miles long, the advantage in respect of result was greatly in favour of Poses.

[1] The amount of this *débris* could be estimated from the photographs exhibited at the Meeting.

Mr. Caméré. At p. 29 the Author expressed the opinion that, seeing the smallness of the fall designed for Port-Mort, recourse might possibly have been had to a more economical type of dam for that site. Notwithstanding the slight fall (8 feet 9 inches), the height of this weir was not less than 18 feet. Now the inconvenience that had been experienced at Port Villez from the employment of high and heavy frames had naturally led Mr. Caméré to reproduce the Poses type at Port-Mort, of which the good working was assured, and which also presented the advantage of being readily adapted to a greater height should the future requirements of the navigation make it advisable. The footway in the Port-Mort weir, like that at Poses, had been made 3 feet 3 inches above the height of the water upheld, in order to allow later on of a lengthening of the hinged curtains, or of the establishment of small supplementary sluices worked by hand, and so augmenting the height of the water by 20 or even 30 inches, which would easily allow of a depth of 13 feet being maintained in the Seine without the least hindrance to navigation. The facility of raising characteristic weirs of the Poses type was an important advantage which ought evidently to be carried to its credit.

Mr. de Coene. Mr. J. DE COENE presented to the Library, as a contribution to the question under discussion, an abstract of his evidence given before the Technical Commission of the Seine, nominated by the French Minister of Public Works; also a report of the Belgo-Dutch Commission, nominated in 1866 to consider the scheme of a weir for the East Scheldt.

From the former of these documents it would be gathered that Mr. de Coene favoured the narrowing of the outlet of the river, the conservation of a vast interior estuary forming a powerful reservoir; and the construction of a new and completely-sheltered entrance to Havre, of such a character as to give deep-water access to that port at all states of the tide. He desired to draw attention to the views as set forth in the accompanying documents of Mr. Partiot, Inspector-General of Roads and Bridges, who had occupied for several years the position of Engineer of the Maritime Seine. Mr. Partiot had executed part of the estuary works, which had given such splendid results, insomuch that Rouen, formerly accessible only to vessels drawing 10 feet, now received those drawing from 20 to 23 feet, and that for sea-going ships freight and assurance at Rouen were the same as at Havre. The present improved state of affairs gave great value to Mr. Partiot's opinions. Mr. de Coene would remark upon the movement of the alluvial matter brought into the estuary by the flood-

tide, and afterwards carried away to great depths in the sea by the ebb. The Author's figures were significant on this head. In 1834, before the embankments existed, the capacity of the estuary below the zero of the marine charts was 433,000,000 cubic yards; in 1854 it was 387,000,000 cubic yards; in 1869 (the embankments having been completed in 1860) it was 490,000,000 cubic yards; in 1880, 441,000,000 cubic yards. That was to say, in 1880 with the embankments the estuary was more capacious than in 1834 without them; while in 1869, in spite of the embankments, and contrary to the opinions of the Havre engineers, the estuary was deeper than it had ever been. All rivers with narrow mouths had deep channels, all those with wide mouths had bars. There was no exception. The Mersey formed an example, as did the Seine at present. It seemed therefore to Mr. de Coene that the Paper was not complete as regarded the estuary. The Author had omitted to mention Mr. Partiot's project, which had been made known to him at the Rouen meeting of the French Association, and which offered a solution of the problem of improving the mouths of tidal rivers. Of all examples the most remarkable was that of the Humber, which had a very deep channel of great width, owing to the narrowing of the estuary. That was what engineers should strive to attain. The Author seemed to have relied too much on official information. He saw the subject from one point of view only, and had not treated it with sufficient breadth, but had kept to the beaten track. The comparison of the accretions and erosions of the estuary was a detail, an important one doubtless, but not one suggesting a general law of evolution. Mr. de Coene.

Mr. de Coene ventured also to cite the Belgo-Dutch report. The conclusions arrived at were worthy of remark. It was laid down, for instance—first, that the ebb of a tide carried off more than the flood brought in; secondly, that all efforts should be concentrated in the current of a single channel. Facts supported these conclusions. That was the solution sought in the case of the Seine. In his communication to the Industrial Society of Rouen, he had considered the estuaries of all the great rivers —Gironde, Scheldt, Elbe, Tagus, Foyle, and Tay—and the comparison had led him to a conclusion which had not once been falsified. In a summary study he had lately made of the river Mersey, he expected to arrive at the same conclusion, the realization of which would be a great benefit to Liverpool, where access was impossible at low water.

Mr. JOHN FOWLER observed that some of the Author's remarks as to the effect produced by the works on the tidal section of the Mr. Fowler.

Mr. Fowler. Seine seemed to be open to objection. The results which had followed the works on the Seine were akin to what had followed similar works carried out in a corresponding manner in this country. Experience proved that accretion followed training-walls or groynes, whether transverse or longitudinal, the accretion proceeding with more or less rapidity according to the quantity of solid matter contained in the water, and ultimately rising to within a foot or two of the height of the training-works. When the foreshore was narrow and the lateral currents were stopped, the surface assumed a curved slope from the shore, but when wide the surface was level as shown on Plate 4, Fig. 7. The works on the Seine had been carried above average high-water level, and probably reclamation was the primary object in carrying them so high. Chalk was not a good material for the purpose, but by repeated making up it was more likely to stand at one-quarter or one-third tide than at full-tide height. At one part of the Tees where the depth of sand exceeded 40 feet, and the current at unusually high tides was over 4 miles per hour, the wall had been made up four or five times; and whilst the average cost of the walls was 28*s.* 6*d.* per lineal yard this part cost £5 5*s.* The accretion beyond the ends of the training-walls was less than might have been expected, considering the large quantity of soil which had been removed from the channel. Between the training-walls the section on Plate 4, Fig. 2, showed deepening ranging from 10 feet to 36 feet over a length of 28 miles, and an average breadth of ¼ mile; so that taking the average deepening and half width there would be more than 80,000,000 cubic yards of soil removed, some of which would no doubt find a resting place round the ends of the training-walls, but the greater part would be carried downward to the lower estuary. No doubt if the training-walls were of full-tide height to the end, permanent accretion would take place under their shelter. It appeared, however, from the Tables given in Appendix II, that the tidal capacity of the Lower Estuary had been subject to great variation prior to the commencement of the works, and that its condition in 1883 was nearly 11,000,000 cubic yards better than in 1853. It also appeared that between 1875 and 1880 accretion took place at the rate of 11,000,000 cubic yards per annum, whilst between 1880 and 1883 it was under 650,000 cubic yards per annum, and probably it had now ceased. These fluctuations were common to all sandy estuaries, and they often extended over long periods in one direction.

In 1762 the sandbanks at the mouth of the Tees and the depth (4 feet) on the bar were almost exactly the same as in 1862. Persons unacquainted with the earlier chart jumped to the con-

clusion that the decrease in depth was due to accretion which had followed the early works of the Tees Navigation Company. No mention was made of any deterioration in the channel beyond the training-walls, and therefore it might be inferred there was none arising from the accretion. Mr. Fowler.

The Author assumed a parallel between the works in the Seine and those proposed for the improvement of the Mersey two years ago. The works proposed in the Mersey, however, differed in three important points from those carried out on the Seine. The training-walls did not terminate in the middle of a sandy estuary but beyond. The training-walls were not proposed to be of full-tide height, but the average height of the sandbanks. The channel was not to be formed by scour but dredged out; instead of 80,000,000 or 100,000,000 cubic yards being driven down to the lower sandbanks, more than 16,000,000 cubic yards of material were to be lifted out of the estuary by dredging. The outer sands at the entrance of the Mersey were entirely separate from the sands in the upper estuary. The narrow channel between Liverpool and Birkenhead gave the direction to the incoming and the outgoing current. Alterations in the form or height of the sandbanks in the bay did not affect the upper estuary, neither did alterations above Liverpool affect the channels in the bay, the tidal capacity remaining the same. The question at issue was, would low training-walls, such as were proposed in the Mersey and had been carried out in the Tees, encourage accretion above their height? The works in the Seine, being so different in character and situation, could give no answer; the works in the Estuary of the Tees showed that they would not.

Mr. E. GARLICK remarked that the training-walls sketched out by the Author in the Estuary below La Rille would, from their convexity, evidently throw the channel from side to side of the new estuary, instead of keeping it always acting in one and the same position, and in a direct course to the sea. At Honfleur the distance between the proposed walls was 1½ mile, and at the mouth of the estuary 5½ miles. In the new wide estuary within the training-walls the channel would wander about without improvement, neither kept to Honfleur nor to Havre. The training-wall 6 miles in length, from Honfleur to Villerville Point, did not exhibit any utility worth the expenditure, for it was parallel with the present shore, apparently exercising no new tidal influence. From an examination of the plan, Plate 4, Fig. 8, he thought the proposal might not injure the navigation down to Honfleur, because there was a possibility of the channel generally remaining Mr. Garlick.

Mr. Garlick. on that side of the estuary; being then at Honfleur, there was little probability of it making across from there to Havre. But what would be the effect at Havre when the Author's north training-wall was put in, and the Pointe du Hoc deep, which extended up the Estuary for 7 miles, had been stopped up close to Havre by this north training-wall; and when the channel of the Seine had taken, and for a long time kept, a southern course, and all along the north training-wall the reclamation behind the wall was completed, and the accumulation of sand had extended over that wall into the Estuary, as there was every probability from the curvature of the line of wall and wide estuary it would do? Would not the effect on the navigation of Havre be ruinous?

Professor Gaudard. Professor J. GAUDARD had been greatly interested in the question of movable weirs, having recently compiled a notice on this subject for the Bulletin de la Société Vaudoise des Ingénieurs et des Architectes. The systems in use on the Seine suggested the following conclusions:—For weirs frequently raised and lowered a footway was generally adopted; now, from the moment that it existed and could render support to the needles, this simple attachment, sufficient for small heights, supplanted the Chanoine shutters. These shutters were still appropriate for navigable passes, but when their height exceeded 10 feet, it was advisable to replace the winch-barge by a movable footway, and hence arose the question of seeking to use the frames (*fermettes*) as supports for the wall of the dam, and so dispensing with the props and trestles of the Chanoine system. This was what had been done by Messrs. Boulé and Caméré; the needles being found too heavy, these engineers had substituted the more-easily managed curtains, constituting formidable competition with the older shutters. The same idea seemed to have inspired Mr. Pasqueau, in his modification of the Chanoine system on the Rhone. The Tavernier system, with an upper fixed bridge, was more ambitious than those with the movable footways. It had been recommended for the Rhone by Mr. Pasqueau, on account of the stones and gravel brought down by that river impeding the lowering of the frames on the bed. This type of weir, in fact, did not allow of any delicate parts lying on the river-bed. There only needed a sill to support the footings of the uprights of the weir. Now, with the Caméré curtains it would not be difficult to disencumber this sill. It would suffice simply to raise the bottom of the curtains a little, to allow of a sufficient rush of water to clear away any deposit. The Poses weir, opened in October 1885, under the direction of Mr. Caméré, had successfully borne the test of the severe floods of the winter 1885–86.

As regarded the Estuary of the Seine, the Author submitted a carefully-studied profile for the extension of the embankments, leaving scope for dredging an entrance to Honfleur, which was justified by the power and economy of modern dredgers. Until some time ago the authorities at Honfleur were not above certain modest expedients, sufficient for the time being. They employed osier baskets, anchored by ropes to submerged boulders, in such a way that the flood-tide overturned each basket, and by making it oscillate and by eddying round it, scoured out a hole into which the mooring-boulder sank deeper and deeper. These floating obstructions therefore induced scouring without reefs, as did fixed piles. With eighty baskets, spaced 16 feet apart on a sand-bank, a trench 650 feet long, 4 feet 2 inches deep, and from 16 to 20 feet wide, had been obtained in less than two days, which trench had afterwards been deepened by flushing. This expedient was only successful in currents running from 3 to 4 knots an hour, where, on the other hand, dredging would be impracticable. It had further been proposed to inject air through tubes perforated at the bottom, in order to break up banks where consolidated. Professor Gaudard.

The motion of the tide removed any bar formed of fluvial sediment, not only because it diluted and easily dispersed such material, but because, by mingling with the river-water, it communicated its saltness, and consequently density, to the latter. In a tideless river, on the other hand, it was probable that the heavier sea-water was confined more or less to the lower parts of the estuary. The river-water, in spreading over the surface and losing its forward velocity, allowed the suspended matter to settle. But the example of the Seine showed that, in default of fluvial sediment, there yet remained the sands coming from the sea to be grappled with. The great means of removing these was still the pendulum-like sweeping of the tide, but inasmuch as the tidal broom swept in two directions, it was necessary that the ebb should have greater force than the flood. Velocity was required sufficient to remove sand-banks, without at the same time being dangerous for navigation. In default of a sufficient excess of power of the ebb, the estuary would get choked up by the sand-bearing waters during storms, depositing their burden in places where the cross-action of contending waters destroyed their velocity; and it necessarily required more power to uplift and impart motion to matter once deposited, than to keep it in motion before deposit had occurred. Thus, the Loire between St. Nazaire and Nantes showed a zone where this action and counter-action was indecisive, and where the anchorages filled up in the most persistent manner, albeit good depths were

Professor Gaudard.

maintained in the estuary, which was more contracted than that of the Seine.[1] The preponderating action of the ebb was assured by the addition to it of the fluvial current while the flood lacked that element. By the same token, it would appear that the smaller the volume of the flood, the greater would be this differential action. Nevertheless, it was well known that the volume of oscillating water was of importance for deepening the channel, although there was no occasion to be anxious about the loss of area for expansion by the cutting off of the spaces behind the embankments. The example of the Humber showed that tidal-capacity did not suffer from the reclamation of land, so long as a countervailing gain existed in the increased depth of the channel. Now it was known how greatly the Seine embankments had assisted the flood-tide, and allowed it to ascend higher inland. The only fear that need be entertained was, that at the period of low-river, when the latter opposed but little resistance, great storms might act occasionally and partially to choke up the estuary, and that, between whiles, the ordinary movement of the tides might not have sufficient power to restore the normal depths. If that occurred, there remained (were it allowable to think of it) an extreme expedient. It was to induce a torrential reflux—a reverse storm-wave; to produce here what had been done on a smaller scale, yet not without serious difficulty, at the port of Honfleur, namely, to organize a flood by the retention of a spring-tide, temporarily imprisoned by a powerful movable weir, and suddenly released after a certain fall of the tide, navigation being suspended, and banks and other works made strong enough to resist the sudden impulse. It was, however, to be hoped that success would be obtained by less vigorous, and perhaps impracticable measures. On the other hand it was proposed to protect the roadstead by an external embankment, which would stop the accumulation of sand from waves and storms. The idea of scouring by retention and sudden release really meant only the increasing at proper times of the most powerful agent already existing. Floods disencumbered and deepened the channel. The same occurred at the first of the neap-tides, when the river rejected the excess of water which it had accumulated during the period of springs, and the ebb, acquiring more force, deepened the channels seaward. The ebb made the channel; the flood, on the other hand, overturned and equalized such irregularities.

It was a curious fact that extensive estuaries were found where

[1] Annales des Ponts et Chaussées. 1878. 5e Série. Tome xvi. p. 563.

they were of no use. He referred to the glacial rivers, the upper Rhine and Rhone, in the Lakes of Constance and Geneva. These waters, denser by their low temperature and the sediment they contained than those of the lakes, had a tendency to plunge under the water of the lakes, rather than to disperse themselves over the surface. Recent soundings had shown that, far from causing bars, their action had traced, for a length of several kilometres, profound ravines in the lacustrine depths.[1] Professor Gaudard.

Sir CHARLES HARTLEY, K.C.M.G., having had occasion to study the characteristics of the Seine as a navigable stream, in the preparation of his lecture to the Institution on "Inland Navigations in Europe,"[2] could testify to the accurate description given by the Author, of the chief features of the Seine, and of the results which had followed the efforts made up to this time to improve its condition as a navigable highway. So far as regarded the canalization of the river between Montereau and Paris, he had no remark to offer, save that, from his own observation, the locks and weirs which had been established in that part of the river since 1860, had effectually overcome all the difficulties and delays which formerly attended the tedious system of intermittent navigation, created by artificial floods of necessarily short duration. In considering the improvement of the navigation between Paris and the sea by the valley of the Seine, three separate modes of treatment at once presented themselves to the mind of the hydraulic engineer:—1. The deepening of the bed of the existing water-way by training-works and by dredging; 2. The construction of one or more lateral canals on one side or other of the Seine valley; and 3. The canalization of the river from Paris to Rouen, and thence by a well-trained open channel to the sea. Each of these plans had been attentively studied by French engineers long before the execution of works of any description was decided upon. Sir Charles Hartley.

The first serious project, after Mr. Cachin's, was that of Mr. de Lamblardie, who, in 1773, proposed to cut a canal on the right bank of the Seine between Havre and Villequier, at an estimated cost of £400,000. This canal was designed to have a length of 31 miles, a width of 121 feet at the water-line, and a depth of 20 feet. Half a century later, Mr. Berigny was charged by the Government to study the numerous projects which had been publicly brought forward up to that period for the improvement of the Lower Seine, and, having done so, he reported in favour of

[1] Bulletin de la Société Vaudoise des Ingénieurs et des Architectes, 1885, p. 53.
[2] The Theory and Practice of Hydro-Mechanics. Session 1884–85. p. 101.

Sir Charles Hartley.

Mr. de Lamblardie's project. He found it necessary, however, to quadruple the sum originally estimated, owing to the great changes which had taken place along the site of the canal, and to the great advance in wages that had arisen since the first estimate was made.[1] In 1825, a Government Commission, of which Mr. de Prony was the chief technical member, recommended the execution of a grand project, based on new surveys and data of every available kind, for the construction of a maritime canal between Paris and Havre. The length of this canal was designed to be 182 miles (120 miles from Paris to Rouen, and 62 miles from Rouen to Havre); its width, 65 feet at the bottom, and its depth 20 feet. The estimated cost was £8,600,000. In 1830, the execution of this magnificent scheme was arrested owing to revolutionary troubles, and was soon afterwards completely lost sight of; partly because the contemplated expense was so enormous, and partly on account of the rage for the construction of railways, which, spreading throughout France immediately after the first introduction of the locomotive into that country, caused all other public works of magnitude to be neglected for a term of many years' duration. Owing to these circumstances, it was not until 1846, as the Author had related, that energetic steps were taken to improve the Seine below Paris. Since that period to the present day, large sums had been spent annually on works connected with the canalization of the river between Paris and Rouen; but in the lower or tidal part of the river, the expenditure on the embankment-works ceased altogether in 1870.

With regard to the canalization between Paris and Martot, by means of which a permanent depth of 10½ feet was on the eve of being obtained, as contrasted with a depth of only 4 feet forty years ago, he should like if possible, to have it explained by the Author, how it happened that the establishment of a depth of 13½ feet, the intended ultimate depth between Rouen and the St. Aubin lock, near Martot, was not aimed at between Rouen and Paris in the first instance? According to the longitudinal section given by the Author, the cost of obtaining an additional metre in depth in the upper ponds by dredging would have been trifling, in comparison with the immense advantages which would have been gained by the admission of vessels, drawing 13 feet instead of 10 feet, into the very centre of the French capital.

The question of resuscitating the scheme of 1825 for the construction of a ship-canal between Paris and the sea could not be

[1] Navigation Maritime du Havre à Paris. Par C. Berigny. Paris, 1826.

profitably discussed in the absence of special information relating to the drainage-levels of the Seine valley; and, moreover, he fully agreed with the Author that it would be wise to wait and see whether the greatly improved waterway between Rouen and Paris, now nearly completed, would not suffice to supply all the requirements of Paris, before attempting to burden the State with an enterprize of very doubtful financial advantage. Sir Charles Hartley.

The Author's account of the training of the river from La Mailleraye (51 miles below Rouen) to Tancarville, La Roque, and Berville, was highly interesting and instructive. The total cost of the work (£1,200,000) including the estimated repairs of the walls, had been small, considering the great benefits the work had conferred on agriculture and commerce. The embankments, although stopping far short of the point designed in 1845 by Mr. Bouniceau, had already accomplished the following results. The minimum navigable depth between Rouen and Havre at high water, at neap tides, had been increased 8 feet, or from 10 feet up to 18 feet, thus allowing the passage of vessels of 2,000 tons at the present time as compared with only 200 tons in 1845. In 1881 the shipping trade of Rouen had increased to 1,472,215 tons, or to treble the tonnage frequenting the port previous to the improvements; and, lastly, 25,000 acres of land had been reclaimed, the value of which was estimated at a much larger sum than the total cost of the works. These substantial advantages, combined with the fact that the bed of the "Thalweg," or centre of the navigable channel, was now lower rather than higher than formerly, were amply sufficient in the opinion of Sir Charles Hartley to justify the embanking of the Seine, even if it stopped short for ever at Berville. He could not therefore agree with the Author that the example of the Seine was a warning to the authorities of other estuaries such as those of the Mersey and the Ribble. It was no doubt unadvisable to terminate training-walls in the middle of a sandy estuary if means could be found to extend them to the sea; but the example of Mr. Bouniceau's uncompleted project alone, would serve as a salutary warning if it could be proved that the great improvements of Berville had only been accomplished at the expense of the navigable channel lower down. It was not his intention to refer further either to the Mersey or to the Ribble, being conscious that his ignorance of the principal elements affecting the regimen of the estuaries of those rivers would render any remarks he might offer thereon entirely valueless.

As in all river works, it would no doubt be possible, judging by

Sir Charles Hartley.

results, to improve on the plan that had been executed for the improvement of the Seine below La Mailleraye. Apparently, for instance, it would have been better to have constructed the walls with greater solidity, and to have widened out the channel more rapidly as it approached Berville, for in the first case the very onerous cost of maintenance, which had been so much neglected, would have been greatly diminished, and in the second, not only would a greater volume of tidal-water have been admitted, but a much better start could have been made at Berville, as the Author had pointed out, for the prolongation of the walls to the sea. Moreover, the too great contraction of the tidal-space had given rise to undue scour, a circumstance which had abnormally deepened the artificially embanked channel over long distances at the expense of the tidal-capacity of the estuary, although not of its navigable channel. The total amount of scour had been enormous, for, taking the longitudinal section as a basis for calculation, the average lowering of the bed of the trained channel had been about 18 feet. Thus the length of channel being 28 miles from La Piette to Berville, and its average width 440 yards, the amount of silt and sand scoured away and carried into the estuary was 130,000,000 cubic yards, a quantity, it might be remarked in passing, nearly equivalent to, though of course in a great measure independent of, the accretion of 137,000,000 cubic yards, which, according to Mr. Estignard, had been deposited during the period 1866–75, from the end of the training-walls to the meridian of Honfleur. Between the latter and the meridian of Cap de la Hève, according to Mr. Lavoinne, the changes which had taken place during the period 1834–83, had resulted in an accretion of 76,239,220 cubic yards, and in an erosion, principally to the south of the Amfard bank, of 20,772,000 cubic yards; and, in connection with this statement, it should be remembered, although a close comparison of old with recent surveys would lead many experts to form a somewhat different opinion, that both Mr. Lavoinne and Mr. Vauthier (who had carried his investigations for upwards of a mile to the west of Cap de la Hève) agreed in deducing from their Tables, in respect to the Outer Estuary, that the alterations in capacity by successive accretions and erosions, resulted from variations in the influence of the natural phenomena producing them, and that these changes have no apparent connection with the great alterations which have taken place in the Upper Estuary.

It ought further to be noticed in connection with the Outer Estuary, that Cap de la Hève and Pointe du Hoc had always been movable points, the first being continually destroyed by the sea,

and the second unceasingly ascending the Estuary. In short, general opinion, based on personal observation, seemed to be to the effect that transports of alluvion from the river were of small account in causing the deposits in the outer estuary, and that their chief source was from matter brought in suspension from the south, aided somewhat by the erosion of the cliffs to the north, the latter action being demonstrated by the well-ascertained movements of shingle along the shore from north-west to south-east. Sir Charles Hartley.

With regard to the effect of the works on the tidal flow, Mr. Lavoinne pointed out that the duration of the ebb-tide having been reduced from nine to seven hours above Berville, the velocity of the outflowing current had been considerably augmented, not only between the walls but for a considerable distance below them. He also referred to the advantage of the waters being driven back higher up stream than formerly by the flood-tide, and to the level of low-water at Rouen being about 1 metre lower now than in 1846—results which compensated in a considerable degree, for the great diminution of tidal-volume passing down the estuary. With regard to the present condition of the estuary below Berville, he further remarked that its contracted width, owing to comparatively recent deposits, had also contributed to increase the velocity of the ebb-tide; and that in this way the deposits had played an important part in maintaining and slightly increasing the original depth of the channel. He did not omit to add, however, that the frequent shifting of the navigable channel between the termination of the walls and Honfleur was still a source of difficulty and danger to shipping, especially in foggy weather, and that the condition of this part of the estuary urgently called for speedy redress.

The action of the training-walls in deepening the river between La Mailleraye and Berville (aided by dredging where, as at the Meules bank, the bed of the river was more or less solid), combined with the result of a long series of investigations relative to the regimen of the estuary, induced Mr. Lavoinne to recommend the completion of Mr. Bouniceau's original project as far as the site of the south wall was concerned; to modify the position of his proposed north wall by reconstructing it on a greatly widened out line between Tancarville and Berville; and thence to prolong the north wall on a line gradually widening from 4,000 feet at Berville to 8,000 feet at Honfleur, and to 13,000 feet opposite Havre; as compared with Mr. Bouniceau's 2,000 feet, 4,000 feet, and 7,000 feet at the same points respectively. In Mr. Bouniceau's project it was calculated that the proposed great contraction of the estuary

Sir Charles Hartley.

between Berville and the sea would have the effect of deepening the channel to 26 feet below zero of the lowest low-tide, by increasing the mean velocity of the current between the walls to 2 knots an hour; but Mr. Lavoinne not only considered it would be impossible to maintain so great a depth, but that the attempt to do so might completely destroy the regimen of the estuary. He was of opinion, moreover, that it would be sufficient for the needs of the navigation if trading vessels were able to ascend to Rouen under the same conditions as at other tidal-ports; in short, that a depth of about 25 feet at high-water of neap-tides, which would only require the lowering of the bed to 4½ feet below zero, would be an ample depth to maintain throughout the channel. With this object in view, he proposed such a width of channel as would ensure a mean velocity of 1½ knot an hour between Tancarville and the meridian of Havre. Sir Charles Hartley would not presume to criticise the project of the late Mr. Lavoinne, who made, it might be said, the improvement of the Seine the study of a lifetime, but he regretted that the late Engineer-in-Chief of the tidal Seine did not consider himself justified in recommending the establishment of a much greater depth than 4½ feet below extreme low-water between the training-walls. For his own part, he considered that a depth of at least 12 feet below zero should be aimed at, a disposition which would involve the establishment of a somewhat narrower channel, and an extension of the pier-heads into deep water; but in his opinion the expense of the additional prolongation of insubmergible walls would be far more than compensated by the greater probability of success, both in an engineering and a commercial point of view, which would attend the operation. Apart from this provision to secure a greater depth, he considered the alignment of the walls to be judiciously planned for securing a stable channel, and for this purpose he could suggest nothing better than the continuously concave southern wall from Berville to the sea. This wall, by completely closing the Villerville channel, which now brought in from the south the greater part of the alluvion deposited in the Outer Estuary, would moreover ensure the maintenance of a single channel directed towards the north-west in the natural direction taken by the ebb-tide. Again, the entrance was at a spot where erosion was more marked than elsewhere, and where the "Thalweg" was as deep as at any former period. These great advantages would, in his opinion, be lost if the Author's proposed bell-mouth plan below Honfleur were adopted, and he thought therefore that the special but minor advantages, claimed by the

Author (but which, however, were not admitted by Mr. Lavoinne) in support of his own plan, were no equivalent for its far greater inherent disadvantages as an agent to secure a permanent deep-water entrance to the Seine. Although Mr. Lavoinne advanced many arguments to show that the prolongation of the training-walls would effectually ward off all danger of injurious silting up in the sea approaches to Havre, it was not pretended that otherwise the extension of the embankments would be of any benefit to that port. It was indeed predicted by not a few engineers and mariners, that the completion of the estuary-works would gravely imperil the conservation of the position it now enjoyed of being the second port in France. Nor was it surprising that such fears were entertained, when it was remembered that the draught of vessels trading to Havre was already limited by the depth of water over a wide zone in front of the port, on which there was a depth of only 26½ feet at high-water of neap-tides; the range of tide being 24 feet at springs and 12 feet at neaps, and the depth at the entrance to the harbour being only maintained at 8½ feet below low-water of spring-tides by constant dredging. On the other hand, the fixity of the bed of the sea in the immediate neighbourhood of Havre should beget confidence; for, comparing together all the surveys which had been hitherto made, the unchangeableness of the bed of the roadstead was proved beyond a doubt. This happy circumstance was due, according to Mr. Lavoinne, to the complete absence of matter held in suspension by the alternating tidal currents, and to the independence which existed between the travel of the shingle coming from the north, and that of sand and silt from the south. To this exceptionally favourable condition of things he attributed the immutability of the deep-sea approach to Havre, and he appeared to have had good reasons for concluding that works, such as he proposed for the improvement of the estuary, would not be prejudicial to Havre so long as the double action of the tides and littoral currents continued to prevail. If, however, contrary to Mr. Lavoinne's expectations, further investigations should give good grounds for apprehending the consequences of prolonging the training-walls across the bar into deep water, it would then be more prudent "to let well alone," and to adopt the safest solution of the difficulty, namely, that of digging a deep lateral ship-canal instead of a barge-canal between Havre and Tancarville, and of restricting the extension of the embankment-works to a judicious *raccordement* of the existing walls with the shores of the estuary in the direction of Honfleur.

Sir Charles Hartley.

Sir Charles Hartley. Three projects among many others for the improvement of the port of Havre were now being warmly discussed in France—1st, the project of a large body of experienced naval officers, for the improvement of the existing port by the construction of a breakwater to protect the small roadstead and the existing entrance; 2nd, the project of the Government engineers to suppress the existing entrance (which was directed south-west), and to substitute a new one turned towards the north-west, and the creation of a tenth basin by encroaching on the sea. The expense of these works was estimated at £3,200,000; 3rdly, the project of Mr. Hersent, which embraced three distinct improvements—*a*. The protection of the small roadstead and the existing entrance by a series of isolated breakwaters, beginning at Cap de la Hève, and extending over a length of 4½ miles (including the width of the six openings between the breakwaters) at an average distance of 1 mile from the shore to a point due north of the Ratier bank; *b*. A continuation up-stream of the line of breakwaters by the construction of an insubmergible training-wall to a point 1,600 feet immediately opposite Berville, and of a south training-wall from the latter to Honfleur, where the width of the channel would be increased to 5,000 feet; *c*. The construction of an insubmergible wall round the Ratier bank, in order to ensure the deepening of the two channels, by fixing the position of the north and south currents which separated the channels at the present time. The total estimate for this comprehensive project was £6,706,000, but it was anticipated that of this sum £4,236,000 would be obtained by the sale of reclaimed land behind the training-walls, thus reducing the total sum to £2,470,000. These projects differed so greatly from each other that no better instance could be given of the diversity of opinion that existed in France as to the best means of improving the port of Havre. Moreover, this important question could never be separated from that of improving the estuary of the Seine, when the latter subject was under discussion, and therefore the port of Havre had been somewhat prominently referred to in his remarks on the Author's valuable Paper on the River Seine.

Captain Hills. Captain GRAHAM H. HILLS observed that the Author had made valuable additions to the facts which in previous Papers he had contributed to the records of the Institution. But in Chapter III. on estuary works he quitted facts to enter the region of speculation, and committed himself to a scheme suggested by the late Mr. Lavoinne, formerly District Engineer for the tidal Seine, stationed at Rouen. The Author stated his objections to some

details of Mr. Lavoinne's scheme, but accepts his main argument in favour of a seaward extension of the existing walls, and produced a design showing the modifications of Lavoinne's plan which he would approve. The arguments as put forward by both writers involved important admissions, which might be thus summed up:— Captain Hills.

1. The deposits which had formed accretions in the Seine were derived from erosions from neighbouring sea-coasts borne by ocean-currents ranging along those coasts, until traversing the opening of the Seine Estuary they were deflected, and their suspended matter was deposited where shelter from prevailing winds was provided by the features of the estuary.

2. Since the commencement of the training-walls in the Seine in 1847 down to 1880, the bulk of the deposits outside of the channel between the training-walls was estimated at 312,000,000 cubic yards; and it was stated by Mr. Lavoinne that eventually the whole spaces now proposed to be cut off from the estuary by the extended training-walls would be filled by similar deposits.

3. It was also admitted that between 1875 and 1880 a large accretion had occurred in the seaward parts of the estuary between the coasts of Havre and Villerville.

On these points he would observe:—

1. As the training-walls were advanced seaward, the conditions of shelter tending to promote deposit were favoured, and as accretions grew the favourable conditions of increased shelter grew also.

2. That the loss of capacity in the tidal-estuary implied by the accretions already recorded, together with that of all future accretions, implied a diminished energy of tidal-stream in the sea-channels, and consequent enfeeblement of the power which tended hitherto to their maintenance.

3. The contention that alternations in the depths of the sea-channels existed before the training-works were commenced, and that losses of capacity similar to those which occurred from 1875 to 1880 used to occur and were subsequently righted by natural causes, was irrelevant, in face of the great changes made in the natural features of the estuary, changes which had altered the effect and operation of natural causes. Assuming, but not granting, that deposits in the sea-channels might have been due mainly to peculiar seasons of storm, the tidal-action being impaired in its outflow by the tidal abstraction already accomplished, the process which formerly operated to clear out such deposits was proportionately enfeebled; it was therefore mere assumption to maintain that the future could develop such alternations as were said to have occurred in the past. The extension of the training-walls as now

Captain Hills. proposed would leave the estuary-channels to continue hereafter their vagrant tendencies within the limits restricted by the walls; within those limits the elevation of the banks would be promoted by the enfeeblement of the powers which had hitherto resisted or counterbalanced the on-shore drift of storms, and eventually, if the importance of the commerce of the country through Rouen seemed to require it, new training-walls would be established forming a narrow channel sufficient to drain off, and to be maintained by, the tidal and upland water of the river Seine, ending on the sea margin of a delta, such margin falling in with the sweep of the coast-line and the ocean-stream which ranged along it.

Mr. Horan. Mr. J. HORAN held that it could hardly be said that the advance made in the science of the treatment of estuaries, with a view to their improvement for navigation, had kept pace with like progress in other departments of modern engineering. Whether this had arisen from the complication of the subject, or that its masters had relied upon individual judgment, followed by tentative work in the few cases successfully treated, without forming or formulating any clear views towards generalization, certain it was that the little knowledge obtainable was to be had only from applying the abstract views of writers on the theory of tides and waves. From the idea of a succession of equal waves in open water, it was only a step to form a conception of the succession of diminishing waves which followed the entry of a tidal-wave into an estuary; diminishing, first, because of the opposition encountered from friction in the channel and other obstacles, and, secondly, from the opposition offered by the descending upland water, and in some cases by a reflected tidal-wave. The diminution effected in this way was not necessarily in all the dimensions of a wave, but related rather to the energy transmitted by a wave to its successor, reckoning from the sea upwards. The phenomena were masked by the great length of the waves as compared with their height, and by interference of the descending upland water when its volume became comparable with the volume of sea-water entering, or with the volume of any of the subsequent transmitted waves. This interference went so far sometimes as to give rise to a bore, just as the mutual opposition of waves produced a chopping sea, or as breakers were formed on a shelving shore, for it must be kept in mind that the oscillation, or to-and-fro movement, produced by a passing wave had its speed lessened on the flow, and increased on the ebb by the descending river. From a consideration of the subject in this light, it followed that there must exist in every tidal estuary, not possessing conditions which might be inferred later on, a state of affairs analogous to what was

known as the head of a tide, namely, a region mostly well marked by deposition and an unsettled state of the currents; but owing to the varying relative quantities of tidal and upland waters, this area was not in all cases easily defined. Works undertaken solely for the improvement of the river above this area would tend ultimately to close the estuary, because if such works, by unduly narrowing the channel, increased the velocity of the upland water, the area of deposition would be prolonged towards the estuary mouth, opposition would be offered to the progress of the tidal-wave sooner after its entrance, and the quantity of slack water in the estuary at every tide would be increased as compared with the volume of the sea-water entering. These effects would take place even when the flow of upland water in a given time bore a small ratio to the incoming tidal water in the same time, for scouring power increased rapidly with increase of velocity. A good river could be formed by treatment of this nature at the cost of destruction of tidal-action in its estuary, but clearly the mouth of such a river would always be a problem requiring solution. On the other hand, works to facilitate the passage of the incoming tidal-wave would have the effect of extending the area of deposition up the river, and would also give due scope to the scouring action of the upland water when the tide was on the ebb. Deposition would in this way become distributed over the entire tidal-channel, and in case of upland floods of magnitude, large quantities of silt might be cleared quite out of the estuary and be deposited at sea. This was the maximum result attainable, and hence the soundness of the most successful practice, namely, extending low-water line as far as possible up the river. So viewed, the vexed question of the relative values of tidal and upland waters as scouring agents became narrowed to a question of relative volumes and velocities. The existing works on the Seine could only benefit Rouen at the expense of the ports lower down, and were a warning of the general necessity for united action on behalf of all the interests affected, as against partial treatment of such an estuary. A scheme to preserve a good entry to Havre and Honfleur should include a modification of the channel above Berville, probably to increase its cross-section by dredging, as being the only means now available, since so much of the tidal room had been already lost by the great accumulations at this part of the river.

Mr. Horan.

Mr. HENRY LAW considered the first division of the Paper as of peculiar interest. The subject of hydrology had received far less attention in Great Britain than it deserved, and unfortunately the systematic study of the hydrology of the river-basins was

Mr. Law.

Mr. Law. rendered impossible by the irrational manner in which the districts for water-supply, drainage, and river conservancy, were determined. Obviously these districts should be determined by the physical features of the country, and the boundaries should be coterminous with those of the basins, or water-sheds. But as a matter of fact they were determined by the fanciful boundaries of parishes, with the most supreme disregard of the situation of rivers, valleys, and hills. The object of conservancy boards was limited to the preservation and improvement of navigation, their powers were confined to the river alone, and frequently to but a very limited portion of that. If there were a controlling board of conservancy for each large river-basin, then systematic observations could be taken as to all the physical characteristics of each basin, the extent of the several subsidiary valleys, and the distances upon the main stream at which the tributaries from such valleys joined it, gaugings of the various streams under varying conditions, the amount and distribution of the rainfall, the proportions of rain evaporated, absorbed, and delivered from the surface, depending upon the geological characteristics of the soil and of the strata beneath, and the inclination of the surface, and whether bare, cultivated, or covered with wood. One most important matter which influenced the volume of the flow of rivers at different parts of their course was the absorptive or otherwise nature of their bed; and whether the level of the surface of the river was higher or lower than that of the water contained in the surrounding strata. In some cases it would be found that a portion of the water of the river was absorbed by the bed, and passed into the surrounding strata, of which instances occurred in the Chelt, the Mole, the Stour near Canterbury, and streams at Mimms in Hertfordshire, which latter had no outfall whatever, but were entirely absorbed by the Chalk. In other, and those the most frequent, cases, the river as it pursued its course was fed by springs in its bed, which might be from the superficial strata, or from deeper-seated beds; as an instance, the Thames derived nearly half its flow from spring-water entering through its bed. Observations showed that the water in the Chalk on each side of the valley of the Thames stood at a height of several hundred feet above the river, and as the river was approached, gradually fell until it attained the same level: and much interesting information on this subject would be found in the discussion upon a Paper by the late Mr. Peter Barlow, M. Inst. C.E.[1]

[1] Minutes of Proceedings Inst. C.E. vol. xiv. p. 42.

Mr. Law.

It would be difficult to over-estimate the advantages which would result if each large river-basin had its conservancy board with the requisite control over both the land and the water within its district, and which had rating powers by which the means could be provided for making the necessary surveys, conducting the necessary observations, and adopting measures for preventing or mitigating floods, and for improving both the drainage and the navigation. The Author showed how much had been done in the case of the Seine to mitigate floods, by the construction of movable weirs, and by the transmission of warnings to the weir-keepers whenever the upper reaches of the river were in flood. Nothing could be simpler than an automatic apparatus to transmit and record electrically the rise and fall of the river at any point desired, however distant that point might be.

The second division of the Paper was most important, and the details there given as supplemental to the Author's former Paper were of great practical utility. There could be no doubt that the rapid and general development of the railway system in this country had led to the inland navigation being much neglected, and that as a consequence the same attention had not been paid as in other countries, to the improvement of weirs, by means of which while a sufficient depth of water might be retained in dry weather for the purposes of navigation, the rapid discharge of large quantities of water in times of heavy rainfall should be provided for, so as to avoid flooding the adjacent country.

The lessons to be learned from the works, described in the third division of the Paper, which had been executed in the estuary of the Seine, were not only of great importance from the magnitude of those works, from the striking character of the results (so different from those anticipated by the projector), and the rapidity with which those results had been realized; but the subject had special interest from the use made of the experience gained in the treatment of the Seine by the engineers engaged in the great parliamentary fights over the proposed Manchester Ship-Canal.

The arguments, which the opponents to the schemes for the Manchester Ship-Canal founded upon the experience derived from the Seine, might be thus briefly stated: From the peculiar contour of the coast at the mouth of the Mersey, the sea was always endeavouring to close up the entrance to the river, and to form a continuous beach extending from the Lancashire to the Cheshire shores. Were it not for the tidal-flow twice every day of the water entering and leaving the mouth of the Mersey, that mouth would be entirely closed; but the constant passage of this water

Mr. Law. forced an opening for its escape, the dimensions of which passage were dependent upon the quantity having to pass. There were here two antagonistic forces in play, namely, the sea constantly endeavouring to close the mouth, and the passing water as constantly endeavouring to force a passage; and these forces were so nearly balanced that sometimes the one, sometimes the other, predominated; the depth of water and the position of the bar altering from time to time, according as the volume of tidal water, or the force and direction of the prevailing winds varied. It had been proposed in the first two schemes to construct training-walls, to form a definite channel through the sandy inner estuary of the Mersey extending from Garston to Runcorn. The opponents of these schemes appealed to the experience gained from what had occurred upon the Seine (amongst other rivers) in support of their contention that wherever training-walls, were they high or low, were made to form a comparatively narrow channel through a wide sandy estuary, the waters of which were loaded with solid matter in suspension, accretion behind such walls was inevitable. And they went on to say that the effect of such accretion in the Mersey would be to diminish the tidal-capacity of the inner estuary, and as a consequence to lessen the quantity and force of the water entering and leaving over the bar; thus giving a preponderance to the efforts of the sea to increase the height of the bar, until the diminished area of the channel over the same had become adjusted to the diminished flow of water. It was also contended, with apparent reason, that these effects would be cumulative; that, as the banks increased in height, it would become necessary to raise the training-walls, which would again cause a further increase in the banks, until the whole of the inner estuary had been raised to the level of high-water. It must not be supposed, however, that those who adopted this line of argument condemned the use of training-walls. In many situations they were of the greatest value, amongst others where it was desired to canalize a river, and where there was either no bar, or where the training-walls could be carried beyond the bar into deep water.

In Mr. Law's experience, increased depth of channel when produced with due regard to the general regime of the river was always attended by increased tidal capacity.

Mr. Partiot. Mr. L. PARTIOT, having been for nine years in charge of the embankments of the tidal Seine, had had opportunities of carefully studying the question. He had presented various schemes which up to the present time had never been seriously examined; per-

haps because they comprised in one project the improvement of the Estuary of the Seine as a whole, entailing a large outlay; perhaps because of the antagonism between the ports of Havre and Rouen, which preferred plans exclusively favouring their several interests. The question having recently been reopened by the French Government, he had taken the opportunity of setting forth his views in a memoir.[1] He had approached the subject from a new side, namely, that of the effects produced by the "narrows," which often separated the estuary of a river from the open sea. It appeared to him quite possible from this point of view to assure a good outfall, while satisfying at once the interests of Havre, of Honfleur, and of Rouen. Mr. Partiot.

He had noticed that when the estuary of a tidal-river, of which the bottom was sandy, was separated from the open sea by a narrow strait, there was produced in the latter a great depth of water, which did not shoal immediately above or below the narrows, but formed channels extending to a considerable distance on either side. He cited in his memoir the outfalls of the Gironde, of the Scheldt, of the Tagus, and of the Mersey, and added that these interior estuaries, which formed in advance of the actual outfalls, remained unchanged for centuries, without being silted up either by the river or by the sea. This rule was equally applicable to bays, such as those of Arcachon and Poole, which only received very small streams. He thus explained this law: When a mass of water, which entered into and retired from a bay passed through a very narrow entrance-channel in a soft bottom, the velocity of the current was augmented, and equilibrium between the bottom-velocity and the resistance of the bed could only be established by a deepening of the latter, varying in extent with the amount of discharge and the width of the channel. The sand in the estuary above was brought down by the ebb through the trench thus produced, and there were formed, by the propagation of this movement, one or several channels, of which the dimensions were dependent on the amount and the duration of the ebb-tide. An analogous cause acted to form, by the flood-tide, a similar channel below the estuary. The sands, thus definitively displaced by the formation of the channels, were deposited in banks above or below the estuary-mouth. In the long extent comprised between the origin of the estuary-channel and its disappearance seaward, the currents did not allow stones, sand, or silt to become stationary.

[1] "Projet des Travaux a faire à l'Embouchure de la Seine. Par L. Partiot, Inspecteur Général des Ponts et Chausées." 4to. Atlas of Plates. Paris 1886.

Mr. Partiot. They moved up and down, and when the river was of such extent as materially to add by its discharge to the volume of the ebb, they were finally carried out to sea. Mr. Partiot thought that if a channel or gullet, such as that of the Pointe de Grâce, at the outfall of the Seine, were made artificially, there would be produced in the gullet great depths, which would be developed into deep channels, over long distances above and below the new pass. Above there would be formed, between Honfleur and Havre, an extended anchorage. The Author proposed to achieve this result by constructing a mole to above high-water mark, between the Amfard Bank and Villerville, a point situated between Trouville and Honfleur. Only a channel of 6,560 feet wide would be left in front of Havre. Nature appeared to have accomplished by herself a similar operation at the outfall of the River Foyle. The works would be completed by training the Seine between an extension of the embankments as far as Honfleur. This plan would admit of the largest vessels entering Havre at any time; of entering Honfleur at every high-tide; and would allow, even at neaps, of vessels of 800 tons ascending as far as Rouen.

Mr. de Préaudeau. Mr. A. DE PRÉAUDEAU remarked that the hydraulic apparatus at the Bougival lock presented the peculiarity that it was actuated by the lowering of the neighbouring weir. This weir had a sill sufficiently high to assure a permanent drop, and situated, on the left bank, there were hydraulic engines, which served to supply Versailles with water. On the right bank there had been installed, within the body of the weir, two turbines, which worked the pressure-pumps. With the ordinary fall of 6½ to 10 feet, a single turbine sufficed for all the work; but when the fall was reduced by floods to about 2½ feet, the use of both turbines at once might be necessary. The turbines might also be used, should the navigation require it, as sources of power for providing electric-light to the locks.

Between St. Aubin and the mouth, the level of the Seine was constantly affected by tidal oscillation, and important modifications in the behaviour of its waters had been observed since the construction of the embankments. At page 38 of the Paper, it was stated that, "The range of spring-tides, which amounts to 23 feet 7 inches at the mouth of the Seine, is reduced to about 10 feet at La Mailleraye, and to 6 feet 7 inches at Rouen;" in 1861, this amplitude was only 4 feet 7 inches at Rouen. At neap-tides, while there was a depth of 11 feet 5 inches at the mouth, the depth at Rouen had been increased from 2 feet 3 inches in 1861, to 3 feet 7 inches in 1875. In other particulars, the regimen of the river had undergone

changes as notable. For navigation, the most favourably situated estuaries were those in which the level of high-water increased regularly and continuously from the mouth to the limit of tidal-action. An example was offered by the river Gironde, which showed that this condition corresponded to great depths near the sea, and to a relatively high rate of discharge of the river. It was not so in respect of the Seine, where the level of high-water springs was, at Quillebeuf, 1 foot 9 inches higher, falling at Duclair to 5½ inches lower, and rising again at Rouen to 8 inches higher than at Havre. Before the embankments were made, high-water rose to about the same level at Rouen as at Havre. The height was less at Quillebeuf, and the depression at Duclair was more sensible. The works having facilitated the action of the tides and of the currents between the embankments, the level of low-water at lowest tides had been decreased between 1840 and 1875 by 2 feet 6 inches at Honfleur, by 4 feet 10 inches at Quillebeuf, by 3 feet 8½ inches at Duclair, and by 4 feet 3 inches at Rouen. From that, it resulted that the difference of low-water levels had varied little between Rouen and Villequier (44 miles), while it had diminished between Villequier and Havre (32 miles). The level of high-water neaps was slightly lowered, it only rose 10 inches higher at Rouen than at Havre, instead of 1 foot 9 inches. It was known that in estuaries as on the seashore, the tides fell lower at springs than at neaps. This did not occur in the tidal part of rivers, when the volume of water sent up by the high-water of spring-tide had not time to pass off so completely between two tides as was the case with neaps. Therefore, the point below which the level of low-water spring-tide was higher than that of neap-tides, defined the limit of the estuary and the beginning of the river. Now this point had changed in the Seine by reason of the works; in 1861 it was 14 miles above Havre; in 1866, 22 miles above, and in 1875, 46 miles above, or midway between Villequier and Quillebeuf.

Mr. de Préaudeau.

The essential difference between the profiles proposed by the Author (Plate 4, Fig. 8), and Mr. Lavoinne (Plate 4, Fig. 9), consisted in that the Author left a channel between the Ratier bank and the south shore, which channel Mr. Lavoinne proposed to suppress. Without discussing the details of the lines to be followed between Tancarville and Honfleur, Mr. de Préaudeau thought he was able, from totally different considerations, to support the Author's views. The flood-tides which contributed to the volume of the maritime Seine, appeared to be derived from two principal directions, an ocean-current traversing the Channel from Cape

Mr. de Préaudeau.

Barfleur to Cape Antifer, and a littoral-current which reached the mouth after having traversed the whole of the Calvados coast west and south of the estuary. The ocean-current first reached Havre and the estuary, it afterwards united with the littoral-current, which was thus conducted at an increased velocity to Honfleur. The mingling of these two currents of unequal velocity, and the decrease of the northern current, produced, an hour and a half before high water, a deviation of the flood-tide before Havre, which took a north-north-westerly direction, hugging the shore. The velocity of these currents bearing seaward augmented rapidly, and attained its maximum shortly after high-water at Havre. Now the embankment of the Seine had produced in the estuary a twofold result—diminution of capacity above the mean level by reason of silting, and lowering of the beds in the channels. From the former cause filling took place more quickly than formerly; from the second cause the ocean-current, which arrived first, contributed the more largely to filling. These conditions did not favour access to the port of Havre, and their aggravation should be avoided. It, therefore, appeared that the profile of the embankments should be so disposed as not to facilitate the introduction of the ocean-current, and not to hinder the introduction of the littoral-current coming from the south. At present three channels served for the introduction of the tide; they were separated by the Amfard and Ratier banks. Both the schemes under consideration suppressed the channel north of the Amfard, and were so far equivalent; but it could not be doubted that the closing of the channel south of the Ratier would be prejudicial to the introduction of the littoral-current. Mr. de Préaudeau, therefore, concurred with the Author, that this channel should be kept open. He would add that, in his opinion, the part of the embankments, projected below Honfleur would not be of immediate utility, nor perhaps, even of future advantage. The displacements of the channel had always originated a short distance from the extremities of the embankments at about 6 miles to the east of Honfleur. If the channel were fixed by a prolongation of the embankments, and conveniently widened as far as the meridian of Honfleur, it appeared possible that the combined action of the waves and of the ebb-tide would be sufficient to maintain west of Honfleur the depth necessary for navigation. Therefore, the embankments should be first prolonged as far as Honfleur, and not beyond that point until after the results of sufficient experience had been ascertained.

Mr. Ridings.

Mr. H. S. Ridings thought that greater prominence should be

given to cheap (and at the same time effective) methods of controlling rivers which were sometimes applicable. Expensive stone training-walls were in many cases out of the question in poor countries, or where the improvements had to be carried out by small companies or boards of conservators. Also in alluvial districts it often happened that stone could not be obtained, except from a great distance and at heavy cost. His experience in connection with the improvements of the Dique entrance of the Magdalena river, in the United States of Colombia, pointed to the fact that rough logs of timber used as piles (driven as a rule very easily) formed an excellent substitute for stone training-walls. The piles need not be driven close together. There was a sensible diminution of the current behind the piles, and as a consequence a deposition of silt. When the deposit had risen to a certain height, means should be taken to protect the edge next the navigable channel in certain parts, either by close piling, by pitching, or by "mattresses." Mr. Ridings.

As was well known, in many tropical countries, rivers which in the wet season were torrential, in the dry season became small streams. Where land was not valuable embankments might be thrown across valleys, or advantage might be taken of natural depressions, to turn a part of the flood-water into them, thus forming lakes, which in the dry season would become feeders to the main channel. Though this might not be of much service for purposes of inland navigation, it would be of immense service for irrigation. If such a system as this could, for instance, be carried out in connection with the Orange River in South Africa, the advantages would be incalculable.

Mr. H. T. H. Siccama remarked that the estuary of the Seine resembled the river Mersey in that it was a river falling into a sea-bay. The true river mouth was at Quillebeuf, up to which point, till the middle of last century, the sea reached. The land reclamation to the west of Quillebeuf dated from 1758, when the Digue Blanche was laid, cutting off the still existing lagoon and surrounding land from the sea. As the volume of water flowing in or out of the river itself could not have sufficient power of scour on the bar, land reclamations in the bay might be a cause of the shallowing between Havre and Honfleur. To cut off more submergible surface would only tend to form a delta lower down, with shifting channels, in a more exposed situation. Mr. Siccama.

Another great point for consideration in estuary-works was the direction in which the tidal-wave approached the coast, as the deepest passes across a bar lay, as a rule, in what might be

Mr. Siccama. called "scooping on the tide." This might be seen by a glance at the North Sea chart of the Dutch coast for instance. Here the tidal-wave, coming up from the Channel with an average current of 3 miles an hour, approached the estuaries of the Scheldt, the Maas, and the Rhine, and the narrows of Texel and Vlieland, in a direction from the south-west to the north-east, and all the deepest passes across the bars opened up against the south-west.

The great scouring agent in these passes was the current of the rising tide, the velocity of which was not due only to gravity or to the head between high- and low-water, as the current continued to flow for a time at any place after the top of the tidal-wave had passed that place. Nothing should be done tending to check this current by suddenly narrowing the bed or deflecting the direction, as in this case the living force was broken, and only the current due to head was left. The ploughing up of the channels was done by the rising tide, and the sand or silt thus lifted was carried out to sea by the ebb-tide. The unsatisfactory results of the works at the new waterway at the mouth of the Maas was due to losing sight of this fact in devising the intended improvement. This entrance opened at right angles, or nearly so, to the direction of the littoral current, which, therefore, instead of rushing up the estuary in nearly its original direction, swept by, while only a portion of the tidal-wave entered the river mouth. The position of the jetties at the mouth, too, caused great disturbance in the current, which formed continually-shifting pools and tortuous channels, which would not have occurred had their heads been parallel or tangential to its direction. In the Seine, the influence of the littoral current would probably be less than in the case just mentioned, as Havre and Honfleur were situated in a bay; but the tidal-wave coming round Point Barfleur would set up a current which must be of importance for scouring purposes.

Mr. Stoney. Mr. F. G. M. Stoney had devoted much time and attention to weirs and sluices[1] during the last seventeen years, and his experience had confirmed him in the belief that no form of fixed obstruction or uncontrollable weir should be allowed in a river. Whatever form of movable weir was used, it should not shut into the water, nor down on the bed of the river, when open. Above all things, the full capacity of the river should be preserved when the weir or sluices were open, and the sills should be at the bottom of the river, and all should open upwards from the

[1] Minutes of Proceedings Inst. C.E. vol. lx. p. 85, and Plate 6.

bottom. As an illustration of these principles, Mr. Stoney had erected, some three years ago, a removable weir consisting of four sluices at Belleck, in Ireland. The object was to prevent the flooding of the Erne lakes, which were about 50 miles long of unbroken water, and in which the winter floods rose 9 feet above summer-level. Had the river outlet from the lakes been simply enlarged and deepened, the existing navigation and mill-powers would have been destroyed; but the large sluices were put up to retain water to almost old summer-level, and of such depth and magnitude as to ensure efficient control of any possible flood. These sluices were simply large wrought-iron doors, which shut down tight against planed iron sills set in the bed of the river, and they were lifted vertically from the bottom clear out of and above the running stream at maximum flood. Mr. Stoney.

The great water-pressure against the gates was so transferred to free rollers, that a pressure of 90 tons on each gate was not perceptible, and one man could at any time work the sluices by hand-power. Each gate was 31 feet 6 inches span from centre to centre of the free rollers, 29 feet 2 inches clear span of opening, and 14 feet 6 inches deep. Mr. James Price, Jun., the Resident Engineer of the works, had recently informed him of the working and effect of these sluices after having discharged three winters floods. Mr. Price had allowed 15 feet 6 inches head of water on the gates, that was 1 foot over the top; but could not feel any difference in pressure on the hand-power over the force required to lift the gates out of the water. The sluices had adjusted themselves perfectly watertight; they never required any repairs. Nor had the least trouble from débris or floating bodies obstructing the rollers been experienced, although there had been a continuous flow up to 700,000 cubic feet per minute through the sluices, often bearing down timber and dirt after the bursting of dams in the works above; everything was carried naturally past, clear of the roller recesses. The whole arrangement of sluices had given complete satisfaction, and the effect in controlling the drainage was all that could be desired. Mr. Stoney added that the additional experience gained from these sluices had more than confirmed all previous expectations as to the working of free rollers on vertical planes, and he saw no practical limit to their advantageous use in very large spans. It was not a question of expediency as to other circumstances and local fitness. As to cost, a movable dam made on this principle would favourably compete with any other structure of like span and depth, while it would be more reliable and efficient. Sluices of this kind

Mr. Stoney. could also be made to allow a large ship to pass through the sluice-openings in a short space of time.

Mr. Wells. Mr. L. B. Wells observed that the information given in the Paper on the hydrology of the basin of the Seine naturally directed attention to the principles which obtained in all river basins. In Cheshire the floods in the River Dane, with sources on the steep hill-sides of West Derbyshire and Staffordshire, partook somewhat of a torrential character, while in droughts the river dwindled to very small dimensions; whereas the Weaver, rising in the pervious strata of the low sandstone hills of Cheshire, and having less fall to the sea, was more equable in its flow, and maintained a good supply of water for navigation purposes even during such dry summers as those of 1884 and 1885. The advantage of a system of communication by telegraph, giving warning of heavy rainfall in the district, established upwards of twenty years ago by Mr. E. Leader Williams, when engineer for the Weaver, and of late supplemented by telephonic communication at each weir, had been fully proved. This enabled the sluices to be worked in advance of floods, and the river to be regulated so as to interfere with navigation as little as possible, and yet provide for the passage of the flood-water. It would be interesting to know in what way the floods on the Seine had been influenced by the navigation-works, which must of necessity include the removal of shoals, if not of bends in the river, as well as the construction of locks and weirs. The results might further help to throw additional light upon the old controversy which arose when the Bills for making the Severn navigable were before Parliament, about the time when the Author's Paper on "Fixed and Movable Weirs" was considered by the Institution in 1880. At that time Mr. Wells mentioned works lately finished and in progress on the Weaver, to provide increased depth for navigable purposes, and to facilitate the passage of floods. Two fixed weirs, by which the water was ponded, were being removed, and eight sluices being erected across the river at Dutton, of 15-feet span, 13 feet deep, with a rise of 9 feet 3 inches at the sluices. Under ordinary circumstances the water flowed over the tops as at the stone weirs, but in floods, by raising the sluices, the river was allowed an uninterrupted flow, and as the sluices were worked from an overhead bridge, there was no danger to attendants, and the necessary work of lifting and lowering could be done effectively, and the river regulated provided the channel below was of sufficient capacity to carry off the flood-water. Following this and minor improvements in the same direction, all tending to the benefit of the navigation, the floods in the

Mr. Wells.

Weaver had been brought under better control, and the flood-level lowered, while no interruption to the navigation had occurred through any failure of the sluices. He noticed that the Engineer for the proposed Manchester Ship-Canal, in his Parliamentary plans, had adopted a similar description of weir for maintaining and regulating the waters of the Mersey for navigation purposes. The Author had in 1880 questioned Mr Wells' view of the trustworthiness of the French movable weirs; but seeing that French engineers were still altering their type, he felt certain there must be some good cause for dissatisfaction. The reports in 1873 by Messrs. W. Forsyth and W. R. Manning, M. Inst. C.E., to the Board of Public Works in Ireland, dealt with the needle-weir, the water-pressure weir, the pontoon-barrage, the drum-weir, and the shutter-weir, each of the systems being in use. The Author stated that shutters had given place to needles and needles to curtains, while now the need was acknowledged of a fixed overhead bridge for working the weir, to which the frames were hinged, not at the bottom of the river, as in the older barrages. The latter type commended itself to him; still the grave objection of a multiplicity of parts remained; these he thought would be liable to derangement, to damage by floating bodies, and to become unworkable during frost. In some ponds on the Weaver, the limit to which the water could be raised had been almost reached, and vessels availed themselves of every additional inch of depth; the water-level had therefore to be closely adjusted, and he had not found any self-acting caps satisfactory. He had tried the cap described by Mr. Baldwin Latham in 1880, and which he had seen working at Nantwich;[1] but there must be a variation of 18 inches in the level of the water to allow a cap 13 inches deep to work, and this exceeded the limit permitted. He had also tried butterfly-valves somewhat similar to those shown in Plate 3, Fig. 8; but found they were not self-acting, and were very liable to foul. He was glad that increased attention was being given to inland water-ways, which, although little considered in this country for half a century, would, he ventured to predict, reassert their worth, and when sufficiently developed prove a great boon to commerce. At present it was next to impossible to obtain goods by canals. They must be freed from railway control, and through routes opened and canals enlarged to a sufficient capacity. It would then be found that for certain classes of traffic they afforded the best means of

[1] Minutes of Proceedings Inst. C.E. vol. lx. p. 95.

Mr. Wells. transport. No less than 1,000,000 tons of salt were taken to Liverpool annually by the Weaver, and not a single ton was conveyed by rail. Water-carriage competed successfully with railways for the conveyance of salt to the Tyne, although the cargo had to be transshipped from a Weaver barge into a sea-going vessel, and then made the circuit of England, a voyage from point to point of 1,000 miles, whereas the distance by railway was only 170 miles. After the Upper Seine had been deepened from 5¼ to 6½ feet, the traffic was stated to have grown 100 per cent., whilst the outlay was not raised more than 50 per cent., and this in France, where the population was not increasing as in this country. He should like to hear the reason for fixing 10 feet 6 inches as the depth of the Lower Seine navigation. He understood the standard canal depth to be 6 feet 6 inches, as adopted on the Eastern Canal of France and on the Upper Seine. A depth of 10 feet 6 inches was needless in the Lower Seine for vessels trading further inland, but not deep enough to accommodate the ordinary coaster. Coasting steam-vessels were rapidly taking the place of sailing-vessels; these required from 11 to 13 feet depth of water. The Lower Seine could therefore only be used by a class of craft whose voyage must be within the limits of Paris and Rouen, or at the utmost between Paris and Havre.

Mr. Wheeler. Mr. W. H. WHEELER considered that the system of flood-warnings described by the Author as carried out on the branches of the Seine might usefully be followed in this country, especially on those rivers which passed through low, flat districts. He had frequently brought this matter before the authorities having control over the Fen rivers, but no steps had been taken to put such a plan in practice. He did not gather from the Paper that the training-works in the Upper Estuary of the Seine had so far caused any detriment to the port of Havre, nor could he see any cause for alarm that such should be the case. On the contrary, it seemed that the channel from the end of the trained-work to the sea had rather improved than deteriorated since the work had been done, the difficulty of navigating this portion of the estuary not arising from the depth of water but from the shifting character of the channel, a defect that had always existed. True, the tidal capacity of the estuary had diminished since the training, but to what extent this was due to the training-works was difficult to determine, as it appeared from Mr. Lavoinne's observations that the capacity of the estuary thirty-two years ago at the lower part was even less than it was now. From the fact that the estuary had deepened below Havre, it would seem as if a portion

of the sand which had oscillated between the upper and lower part of the estuary had now become fixed in the upper part, and the estuary to this extent permanently improved. In this, as in all other similar estuaries, there was a large mass of sand lying about the entrance which was driven in occasionally by storms, to be washed out again by the ebb-current. Although, no doubt, the actual power of the waves and of the tidal-current to move sands was greater than the ebb, yet, taken continuously, the ebb-current must have the greatest effect, as not only had all the tidal-water poured into the estuary and up the channel of the river to return again, but in addition there was the fresh-water from the drainage of a very large area of land, this ebb-current having also the aid of gravity to assist it in carrying the deposit outwards. There was also a large mass of movable sand in the estuary through which the channel appeared to alter its course from time to time, owing to the prevalence of wind from one particular quarter, or to the influence of long-continued floods. The strength of the ebb-current was dissipated in moving these sands and forming new channels. If instead of having to move these sands laterally, the whole energy of the flood and of the ebb-currents were concentrated in one fixed channel, their force would be employed in scouring and deepening it, and thus improving the low-water channel and giving greater navigable depth at high-water. Any loss of scour due to the decrease in the tidal-capacity would then be more than compensated. Mr. Wheeler.

For the benefit of the navigation of the lower estuary, it was no doubt desirable to continue the training-works as originally intended, and so fix a deep-water channel in one course, and there would not seem to be any insuperable difficulty in doing this so as not to injure the channels either to Havre or to Honfleur. There was every possibility that they might be deepened and greatly improved. The line of training recommended by the Author seemed open to the objection that owing to the convex form of the proposed north training-wall, the current would pursue a course along the south side and so away from Havre. The line laid down by Mr. Lemire seemed best adapted for serving both Honfleur and Havre. The partially concave line of wall on the north side would probably draw the flood-tide along it, and the ebb would then return along the same course as being the deepest channel. It would be better perhaps if the concavity were continued further on, to opposite Honfleur, and to let the concavity meet the ebb-current nearer the more confined channel. By thus bringing the influence of the ebb-current to bear more directly on

Mr. Wheeler. the channels past Honfleur and Havre, a deep and stable channel would be maintained, and the zone of sands which now existed in the centre of the estuary as a movable mass, would remain fixed in one position.

Mr. Wiswall. Mr. F. WISWALL agreed with the Author that, in point of magnitude, British rivers might not afford opportunities for works comparable with some of those on the Seine; but on the other hand, he believed their capability had yet to be developed, and that they would be found to be at least equal in importance.

The subject of movable weirs had been under his personal observation for some years in connection with the Mersey and Irwell navigation, on which, within the last three or four years, movable weirs had been introduced of a type entirely novel, and which seemed to possess, but in a higher degree, every advantage attributed to the French weirs. This was so whether in regard to their mobility, or adaptability to the different and hitherto frequently conflicting demands of navigation and drainage, or in their power of discharge at the top with a non-liability to silt at the base; or in their indifference to the action of floods, which so far from hindering, were pressed into service as an aid to the practical removal of the weir altogether; or in their simplicity of action, and independence of intricate machinery; or in the entire absence of a super-imposed bridge or head-gearing of any kind—a feature which was absolutely unique in the history of movable weirs, supplying in flood a navigable pass over the whole width of the river. As to opening or closing the weir, it need only be said that a weir, 140 feet wide and 10 feet deep, could be either put in or taken out of action in half an hour. The extreme cost of weirs of this type already constructed had not exceeded £50 per lineal foot. The tilting-weir, of which those existing at Throstlenest and Modewheel on the Irwell, near Manchester, and at Warrington, on the Mersey, were examples, was designed to effectually impound the water for navigation, to admit of being either slowly or quickly opened as required, and to give a full and free passage to the river when floods or other circumstances made it desirable. The weir (Figs. 8 and 9) consisted when closed of a series of rectangular sluice-gates turning on a common axis; when opened they were suspended horizontally, and each gate was capable of being worked independently of all the rest. Three edges of the gates made a watertight joint, two by contact with each other, and pressure upon the projecting flanges of the supporting pier, and the third edge by resting upon the floor of the weir. The river-bed was laid with a sheathing of

stone and timber, and was perfectly level. At intervals of 10 feet Mr. Wiswall.

FIG. 8.

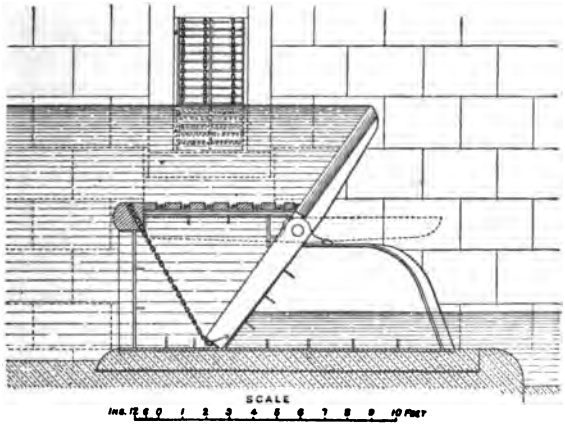
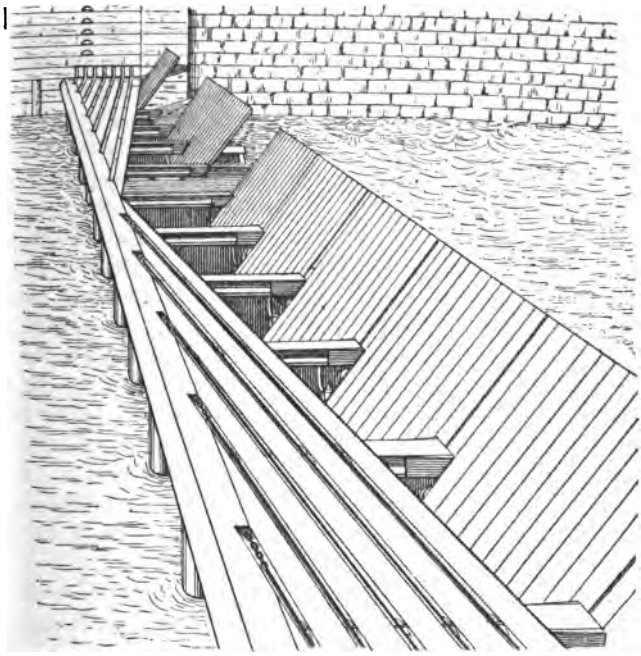



FIG. 9.



from centre to centre, across the bed of the river, cast-iron piers

Mr. Wiswall. were erected, with flanges for securing the piers to the river-bed, and for supporting the tie-beam which extended from shore to shore, and the key-pedestals in which the axle-shafts were set. The turned shafting, on which the gates hung and turned, was in lengths of 10 feet, which reached from pier to pier, terminating in dumb-pedestals keyed to their several seatings on the piers. The gates were framed of English oak, and planked with pine, and were 12 feet long; 10 feet wide above the axle, and 9 feet wide below the axle. A separate draw-chain was attached to the centre of the foot of each gate; it was passed round a grooved pulley secured to the tie-beam, and thence in a straight line to a wall-box, where it was deflected upwards round a grooved pulley to a multiple crab, by which the gate was raised. There were two multiple crabs; one on each side of the river, and each connected with a set of gates. The crabs consisted of sets of three-motion gearing with barrel; that was, one set for each gate-chain. The first motion-shaft, to which the handles were attached, had sliding pinions to enable any one or more of the sets of wheels to be geared to it; the remaining wheels ran loose on the shaft. Rachets were provided to fasten each gate open as it was raised.

The weir had aroused considerable attention in the neighbourhood, and an indication of opinion was obtained from the fact that the Manchester Corporation had decided to introduce two weirs of this type on the River Medlock, as a corrective to the rapid and disastrous floods to which that stream was peculiarly liable.

Mr. Vernon-Harcourt. Mr. VERNON-HARCOURT, in reply to the correspondence, imagined that the greater depth of 13½ feet, secured at high-water neap-tides between Rouen and St. Aubin, than in the river above, inquired about by Sir Charles Hartley, must be due to a desire to provide in this tidal portion a minimum depth, at most states of the tide, equivalent to the 10½ feet which would be permanently maintained in the non-tidal canalised river up to Paris. The greater depth proposed for the navigation up to Paris, as compared with the normal depth of 6½ feet aimed at for the other French waterways, referred to by Mr. Wells, was, he presumed, intended to facilitate the passage of larger vessels, for the important trade between the sea and the capital of France, than could be economically provided for on the other less important lines of inland navigation.

He thought that answers to Mr. Caland's questions were really contained in the Paper itself. As the tide reached Rouen fifty-eight minutes earlier than formerly (p. 38), it was evident that it flowed up to that extent with greater velocity, owing doubtless to

the removal of the shoals which originally impeded its progress. Since, however, the tide rose only an inch or two higher at Rouen than formerly, manifestly the limit of its flow could be but little altered, which might be accounted for by the advantage afforded by the deepening of the bed being counteracted by the undue contraction of the channel. He agreed with Mr. Caland in attributing the changes in the tide at Havre mainly to the changes effected in the Estuary by the training-walls (p. 41). Mr. Caland, whilst expressing a general preference for Mr. Lavoinne's scheme, suggested placing the southern training-wall further out into the Estuary opposite Honfleur, which was in accordance with the plan proposed in Plate 4, Fig. 8. Moreover, though Mr. Caland objected to the rapid widening-out of his proposed training-walls towards the mouth, it was less abrupt at the outlet than Mr. Lavoinne's. There was no necessity to contract the channel opposite Havre in order to deepen it, as there was an ample depth there at the present time; but it was very important to offer no impediment to the influx of the tide, and to restrict the tidal capacity as little as possible. Mr. Vernon-Harcourt.

Mr. Partiot's scheme, proposed originally in 1859, and recently published, should have been included in the list of projects for completing the training-works in the Estuary of the Seine, and he was glad that it had been referred to. Mr. Partiot proposed to prolong the training-walls down to Honfleur, and to build out a breakwater from Villerville Point towards Havre, so as to contract the mouth of the estuary to a width of 6,560 feet alongside Havre. Mr. de Coene appeared to agree with Mr. Partiot in the opinion that a restriction of the mouth of an estuary was the proper method for improving tidal rivers; and they quoted the natural configuration of the Mersey, the Humber, and other rivers in support of their views. He was surprised to hear the Mersey held up as worthy of imitation, for he regarded it as most unsatisfactory, with its shallow channels both above and below the narrows (Fig. 7), and peculiarly difficult to improve. Undoubtedly the narrowing of the mouth of the Estuary of the Seine, proposed by Mr. Partiot, would at first promote scour, and increase the depth in that part of the channel, and for a little distance above and below. This contraction, however, would impede the influx of the flood-tide, and cause changes in the velocity of the current through the narrow neck and in the wide estuary above, promoting the deposit of the silt brought in by the tide. This accretion would be greatly aided by the prolongation of the training-walls to Honfleur, so that eventually the greater

Mr. Vernon-Harcourt.

portion of the Estuary comprised between Tancarville, Hoc Point, and Honfleur, would be raised to high-water level. This large reduction in tidal capacity would reduce the tidal current through the narrowed entrance, and consequently diminish again the depth in the channel. Moreover, this reduction of tidal flow in and out of the Lower Estuary would would favour the natural heaping-up action of the sea on the sands outside; so that eventually, not only would the initial deepening of the narrowed outlet be lost, but the good depths in the bay outside the Estuary would be imperilled. He believed that the wandering of the channel, by periodically stirring up the silt and thus preventing its consolidation and facilitating its removal by the ebb, was the only cause which prevented the silting-up of large embayed estuaries like the Mersey. If the channel were fixed by training-walls, or any other means, the Estuary outside the training-walls would remain undisturbed and gradually silt up, till the interior sluicing-basin relied upon by Mr. Partiot for scouring the outlet channel would be lost. He was therefore of opinion that Mr. Partiot's scheme, by restricting the tidal flow, would be only temporarily advantageous to Havre and Honfleur, and would finally leave the Estuary in a less satisfactory state than at the present time.

It had been suggested by Sir Charles Hartley that the prolonged training-walls should be placed closer together and carried further out than proposed by Mr. Lavoinne, to secure a greater depth; but this would be treating the Estuary too much like a tideless river, and, by restricting the tidal-capacity, would be prejudicial to the maintenance of a good depth in front. He agreed with Sir Charles Hartley that the training of the Seine was fully justified by the results, though the lines and widths adopted might have been modified with advantage; and he only considered that the works served as a warning, from the very unexpected amount of accretion which had so rapidly followed, and especially for estuaries whose maintenance almost wholly depended on tidal scour. Sir Charles Hartley and Mr. Fowler had referred to the considerable scour of sand from the bed of the trained channel as greatly affecting the accretion in the Estuary; but, as he had previously pointed out, Mr. Estignard had made allowance for the increased capacity of the channel, so that the volume of accretion given referred to sediment brought in from the sea, and not to material scoured out of the channel.

Though Captain Graham Hills objected to his drawing conclusions from the facts which he had obtained, a duty incumbent on every engineer, he was glad to find that when Captain Hills

entered himself into the region of speculation, his views as to the clearing out of deposit in the Outer Estuary not being equally effected in the future as in the past, owing to the reduction of tidal-capacity, agreed exactly with the opinion expressed on p. 42 of the Paper. He could not, however, endorse Captain Hills' assumption of the injurious effects that would result from the proposed extensions, and that a further contraction of the channel would be necessary. He believed that some reduction in depth might occur in the deeper channels beyond the training-works, but that an equilibrium would be restored before any injurious silting-up took place outside; and that the channel between Berville and the outlet must be much improved by the proposed extension. Mr. Vernon-Harcourt.

The Pointe du Hoc deep, referred to by Mr. Garlick, hugged a convex shore at the present time; so that it might reasonably be anticipated that the tidal influx producing it would run close along the northern convex training-wall proposed. The channel, moreover, of the Seine, as recently as 1880 (Plate 4, Fig. 1), did not follow a southern course; and the accumulation of sand had not extended over the existing training-walls as Mr. Garlick suggested. He could not therefore admit Mr. Garlick's conclusion as to the ruinous effect on Havre, based, as he believed it was, on incorrect premises.

The fact that the training-walls below Tancarville were low walls, had been ignored by Mr. Fowler, though it was very plainly stated on p. 37 of the Paper. Mr. Fowler had also assumed, in spite of the evidence on Plate 4, Fig. 1, that the foreshore, behind the training-walls, in the wide estuary was flat, whereas at a short distance from the back of the walls it sloped up rapidly to high-water level. He was also quite mistaken in supposing that reclamation formed any part of the object of the works; and he might see in Mr. Bouniceau's book how little the accretion was anticipated when the scheme was proposed. In drawing any conclusions from Appendix II., it must be remembered that it only related to the portion of the outer estuary beyond Honfleur, some miles below the ends of the training-walls. Mr. Fowler was quite right in noting that it had been intended to dredge out a channel between the proposed training-walls in the Mersey; but he believed that scour would have effected the deepening, and removed the material to another part of the estuary, before the dredgers could have been set to work. As Mr. Fowler said, the question at issue in the Mersey controversy was whether low training-walls would promote accretion beyond their own height; they had

Mr. Vernon-Harcourt.

unquestionably done so on the Seine, and there was an absence of sufficiently exact information to determine what had been the result of the low walls in the Tees, which was the only estuary he knew of where it was contended that no accretion had resulted from training-works. He thought that the exception, if it really existed in the case of the Tees, of which there were serious doubts, should not be accepted as the rule.

The chief criticisms had been directed to the training-walls, which formed the most interesting of the Seine works, because the most uncertain in their results. Though the criticisms differed greatly, he thought that they were valuable as representing every phase of opinion which might be considered in deciding on the question. Wherever the training-walls were extended, fresh accretions must occur behind them; and the difficulty consisted in devising such a scheme that the training-walls should be near enough together to improve the channel down to deep water without unduly restricting the tidal flow. Some engineers objected to training-works as injurious to the tidal capacity of estuaries, which would put a stop to their improvement; whilst others would place them close together to insure a deep fixed channel, which would greatly reduce the tidal flow, and produce a sudden change of velocity of the current at the outlet. The object of his suggested extension was to enforce, rather than to impede, the influx of the tide, whilst regulating and improving the channel in the neutral zone where the influences of the flood and ebb were irregular and deficient.

23 February, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The discussion upon the Paper, "The River Seine," by Mr. L. F. Vernon-Harcourt, occupied the entire evening.

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2 March, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate Members have been transferred to the class of

*Members.*

HENRY OSBORNE BALDRY.
WILLIAM WORBY BEAUMONT.
JOHN RICHARD BRITTLE, Wh. Sc.
JOHN BREEDON EVERARD.
GEORGE FREDERIC HAMMERSLEY HEENAN.
THOMAS HORN.
LUKE LIVINGSTON MACASSEY.
HENRY MILLER, Jun.

The following Candidates have been admitted as

*Students.*

ROBERT OGILVIE NEWTON ANDERSON, B.A., B.E.
EDWIN SOUTHEY BEALE.
GEORGE ARTHUR BECKS.
ERNEST HERBERT BURTON.
FRANCIS PHILIP STAINTON CLARKE.
ANDREW DUNCAN.
AMBROSE LEOPOLD EDE.
FREDERICK CHARLES EVERETT.
EDWARD FROBISHER.
CHARLES HENRY GALE.
CHASEMORE PHILIP GATES.
JOHN FREDRICK HARRISON.
HARRY HUNT PEVERIL LE MESURIER.
ALFRED ERNEST LETHBRIDGE.
HARRY MORLEY MILLER.
JAMES ALEXANDER PARKER, B.Sc.
ROBERT SPENCER PERFECT.
FREDERICK WALTER THEODORE SAUNDERS.
THOMAS BOUSTEAD SIMPSON, B.A.
FREDERICK WILLIAM WAREING.
HENRY BOURCHIER WREY.

The following Candidates were balloted for and duly elected:—

*Members.*

ROBERT COLLARD.
CHARLES JOHN GALLOWAY.
THOMAS RIDLEY HETHERINGTON.
JOHN DUNLOP PARKER.
THOMAS WILLIAM TRAILL.
ROBERT REEVES TUTHILL, B.A.
HENRY WOODALL.

*Associate Members.*

JAMES RANSON BAASS. Stud. Inst. C.E.
FREDERICK WILLIAM BRICKNELL, Stud. Inst. C.E.
WALTER HOPE CAMPBELL.
WILLIAM DAWSON.
THOMAS CLARK DEVERELL.
ROBERT FISH.
FULWAR CRAVEN FOWLE.
ALFREDO JOSÉ NABUCO DE ARANJO FREITAS.
JOHN HALLIDAY.
RICHARD JAMES HARTLEY, Stud. Inst. C.E.
WILLIAM ROBERT PAUL HEDERSTEDT, Stud. Inst. C.E.
HENRY CHARLES TERRETT HUNT, Stud. Inst. C.E.
CHARLES EDWIN JONES.
HAROLD JONES.
HARRY HERBERT LAKE.
CHARLES JOHN EDMONDS LARGE, Stud. Inst. C.E.
JAMES MORE, Jun.
JOSIAH PIERCE, Jun., B.A., Stud. Inst. C.E.
CHARLES HENRY PRIESTLEY.
FREDERICK PURDON.
KENNETH REID, Stud. Inst. C.E.
MARTYN NOEL RIDLEY, Stud. Inst. C.E.
STEPHEN PRESCOTT WHITE D'ALTE SELLON.
HARRY ERNEST WALTERS, Stud. Inst. C.E.

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The discussion upon the Paper, "The River Seine," by Mr. L. F. Vernon-Harcourt, occupied the entire evening.

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PLATE 1.

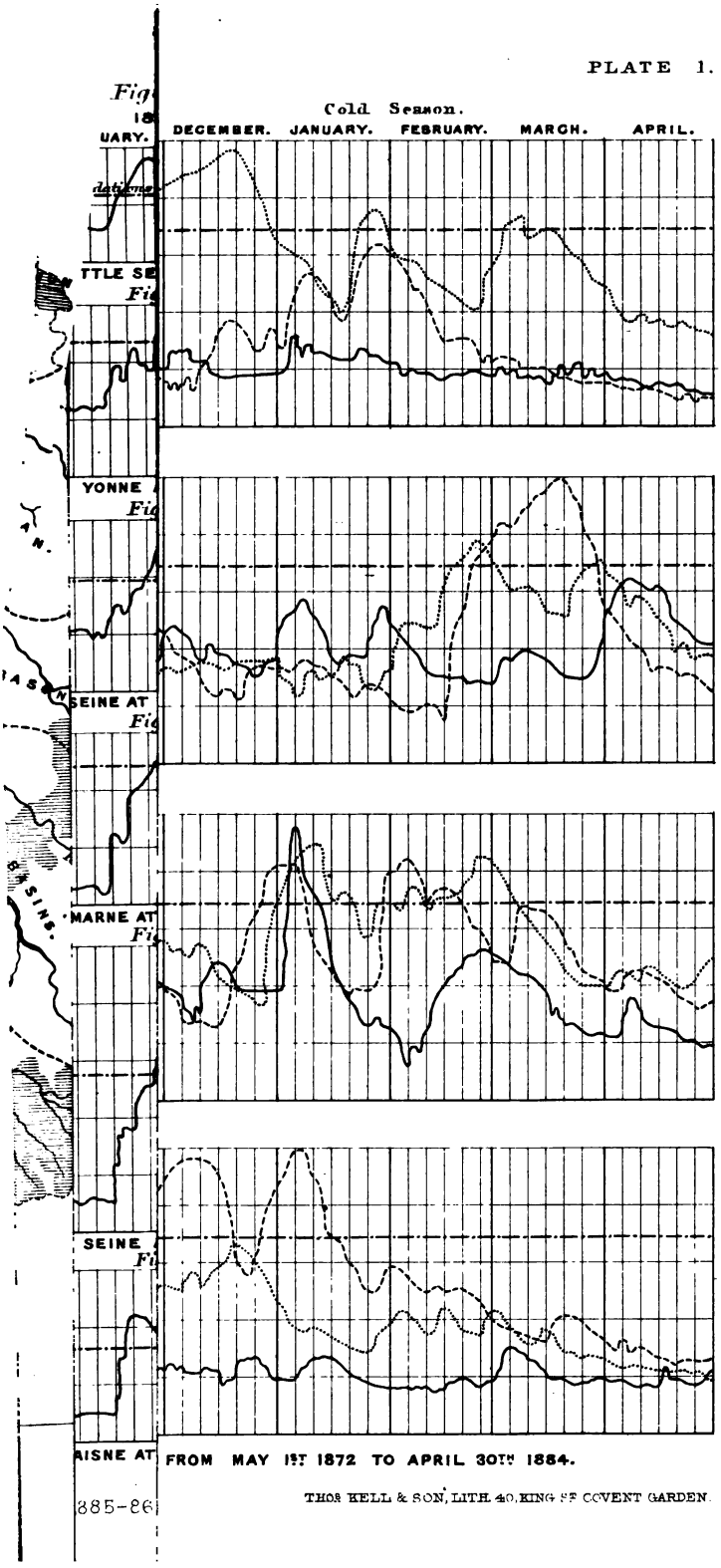
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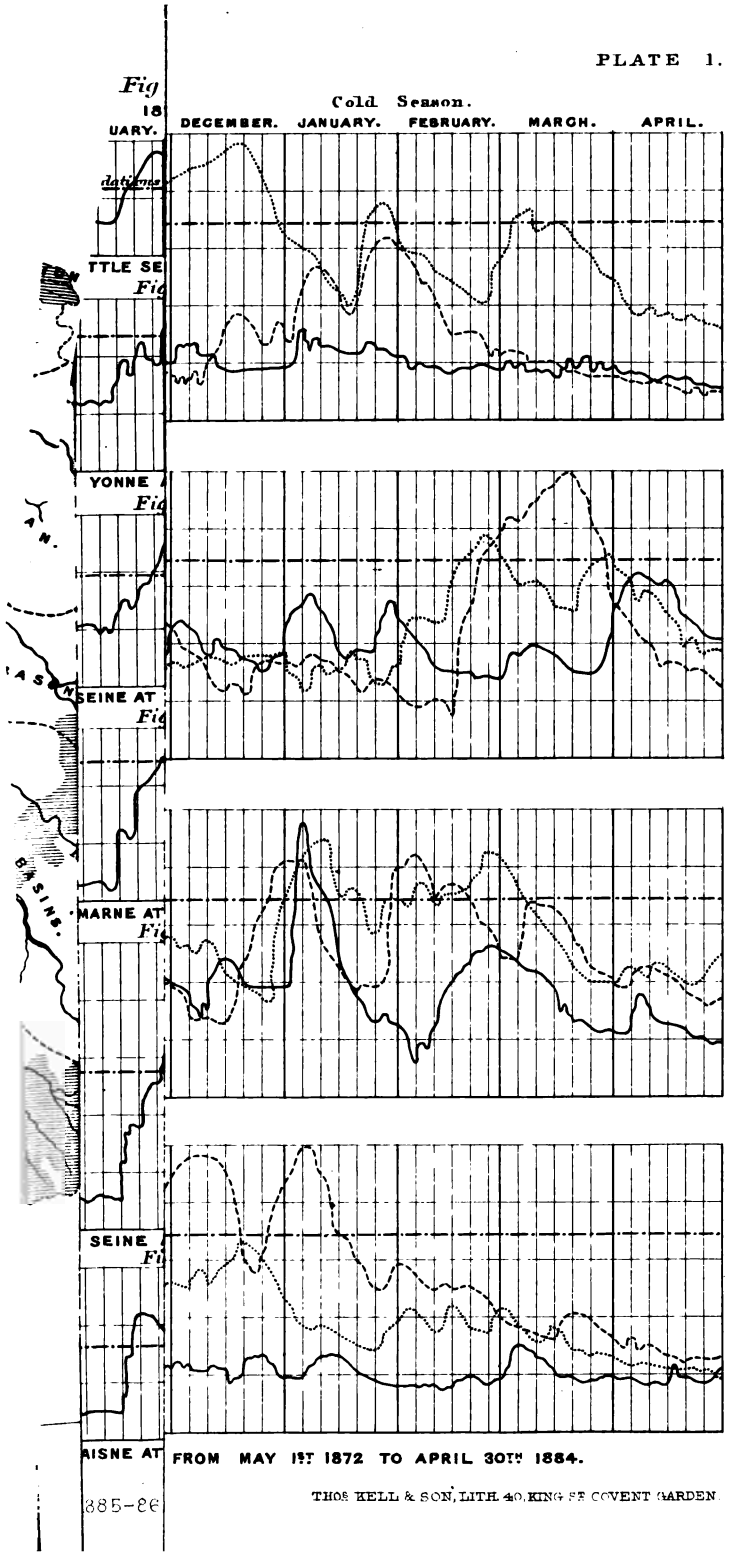
PLATE 1.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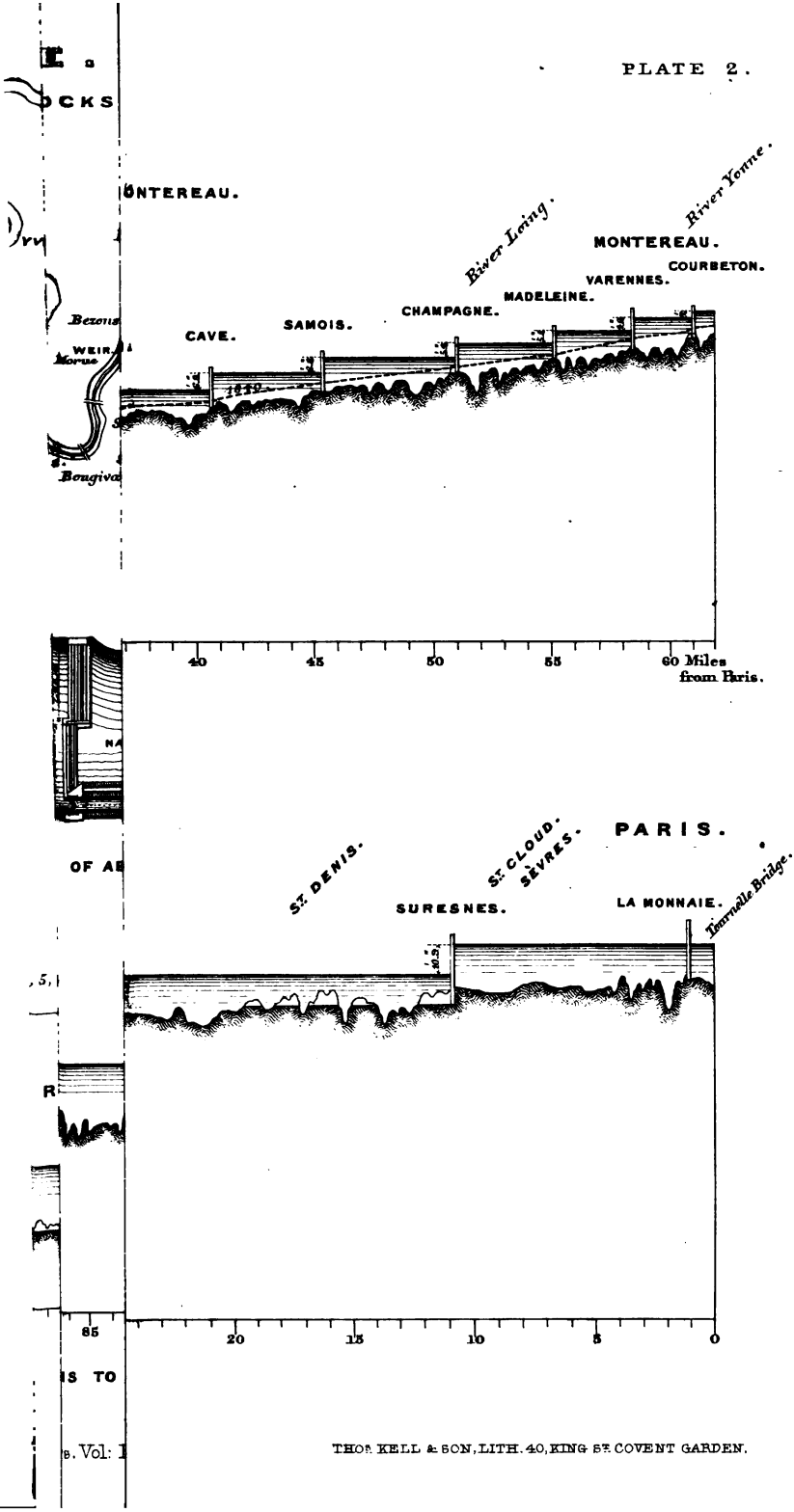


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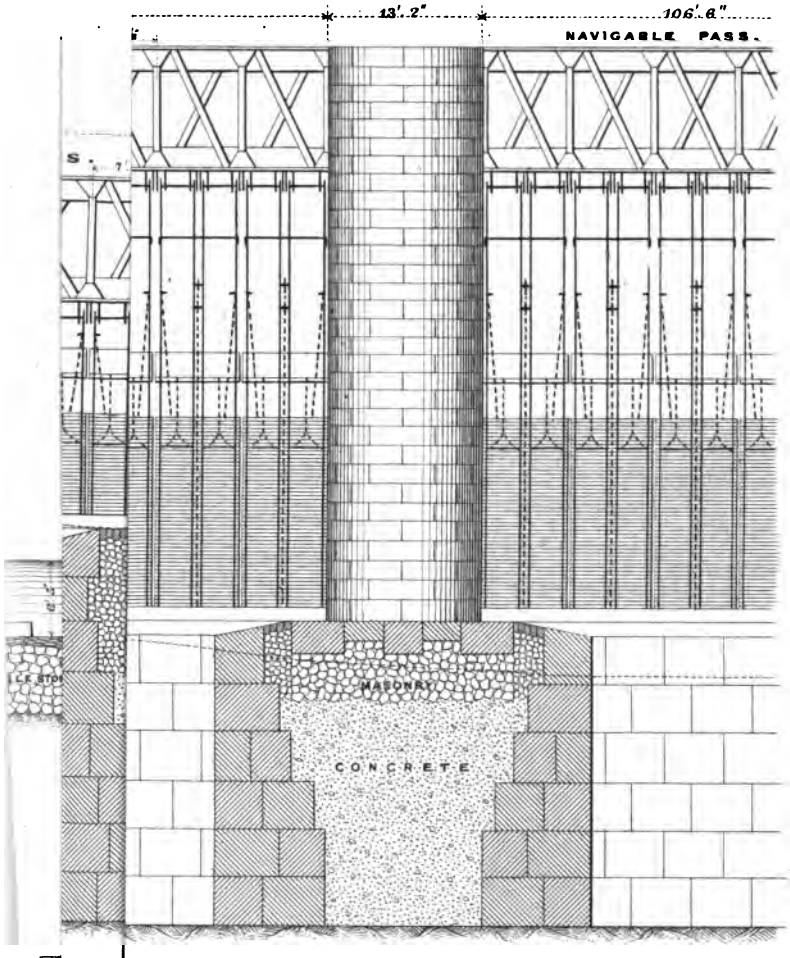


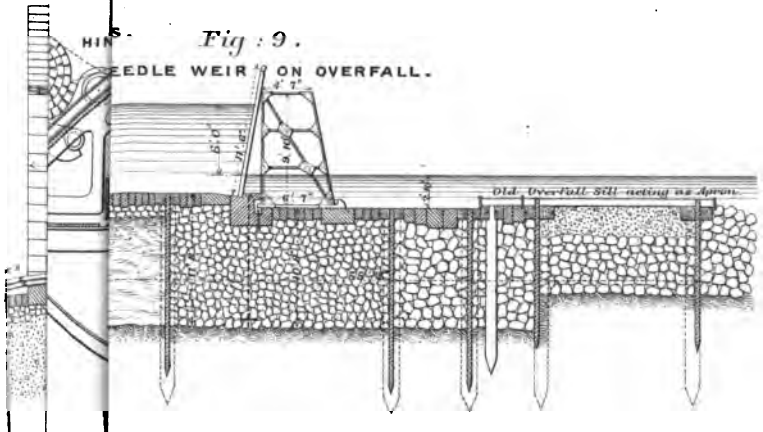


*Fig : 9.*

NEEDLE WEIR ON OVERFALL.



THOS KELL & SON, LITH. 40, KING ST. COVENT GARDEN.

*Fig : 9.*

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HOWING ESTUARY 1883.

PROLONGATION OF TRAINING WALLS.

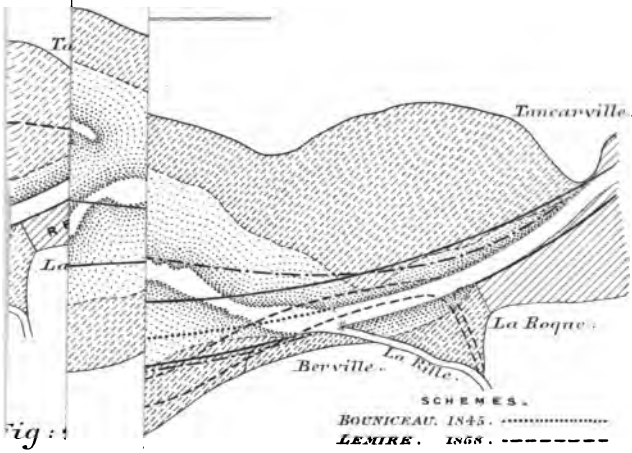
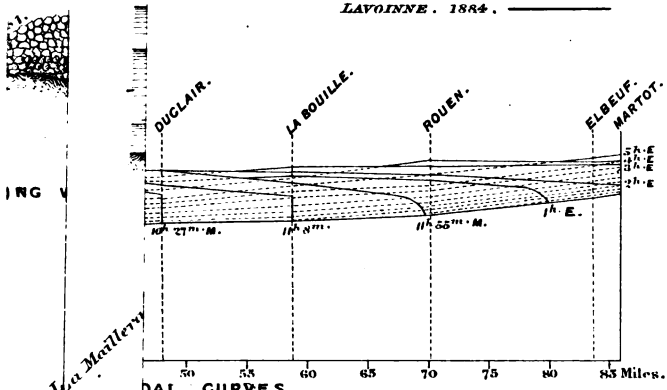



*Fig :*

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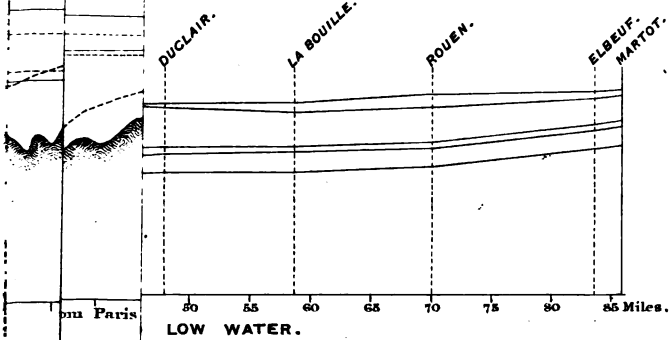
DAL CURVES.

*ptember, 1876.*




LOW WATER.

*Sd 26th September, 1876.*

1885

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